A PROGRESS REPORT ON

PROJECT POCIBO

COSMIC RAY GROUP

School of Physics and Astronomy

UNIVERSITY OF MINNESOTA

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John R. Winckler

Principal Investigator

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School of Physics and Astronomy
University of Minnesota
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I. SCIENTIFIC PURPOSES

The principal motivation for conducting the Pocibo program is the possibility of obtaining by radio telemetry, scientific data for long periods of time from a balloon near the top of the atmosphere. In the past, balloon flights have given data from times ranging from 3 hours in the wintertime up to 40 hours in the summertime. These times are determined by the line-of-sight range for ultra-high frequency radio telemetry circuits which have been used for many scientific flights. Although the long range tracking of balloons has been carried out for meteorological purposes using high frequency radio communication with signals reflected from the ionosphere, the amount of scientific information which could be transmitted has been small. The Pocibo program is designed to utilize the polar vortex wind system. In this system the balloon would drift around the polar region and would be in continuous radio contact with a number of tracking stations situated in the Arctic. Such a high altitude monitoring station has many desirable features. For particle measurements and some atmospheric physics studies, it is particularly valuable in the Polar region. The type of investigations which were originally proposed and for which experiments were constructed and flown on this program include the measurement of low energy primary cosmic rays using particle detectors to separate the isotopes, the measurement of the total cosmic ray ionization, and studies of the time variations and the positional variations of the cosmic radiation at points both close to and somewhat removed from the geomagnetic pole. Such studies are particularly appropriate for the period of sunspot minimum activity when the low energy primary particles increase in intensity. Another particle type phenomena for which measurements were attempted is the x-rays produced by electron precipitation from the magnetosphere. These are associated with the aurora and with processes in the outer parts of the earth's magnetic field and can be measured and studied in the polar regions. Atmospheric studies of ozone, atmospheric infrared temperature, and the electric field gradients at balloon heights appeared to have many interesting possibilities and were also included on some attempted flights. The relation of these atmospheric factors to the stratospheric polar warmings might produce an important link in this meteorological phenomenon. It was hoped, also, that the radio direction finding proposed for the project would be precise enough so that the trajectory analysis of the balloons would add significant information to knowledge of the polar circulation. The air mass trajectory provides an independent method of studying the circulation which otherwise is obtained from individual meteorological soundings from stations distributed over the polar regions.

The principal interest of the group at the School of Physics and Astronomy, University of Minnesota is the particle measurements, and considerable effort has been put into the detectors and other devices flown on the Pocibo payload for this purpose. The fundamental problem of interest is the study of the solar cycle modulation of galactic cosmic rays. It has been known for several solar cycles that the primary radiation has a negative correlation with the solar indices shown, for example, by sunspot numbers, and that the relative modulation of the primary cosmic rays is sensitive to the rigidity of the particles, being high for the low rigidity particles and small for the high rigidity particles. Measurements over several solar cycles with high altitude ionization chambers have shown that during a brief period at solar quiet, the ionization shows a rapid increase with decreasing altitude close to the top of the atmosphere. This and other direct particle measurements show that the low energy particles return only near the period of sunspot minimum. The object of the investigation is to measure these low energy primary protons, α-particles and other nuclei, to study their time variation during this period, to detect any spectral changes, to account for the unusual phenomena seen in the total ionization and, in general, to observe the various features of the solar modulation. In particular, the Pocibo balloon which had the planned capability of remaining airborne for many days could have studied the time variation of these low energy galactic particles in relation to solar activity and in relation to the asymptotic direction in space of the trajectory of the particles which reach the balloon as the earth rotates for the 24-hour period. This would give some clues as to the spatial distribution of these particles outside the magnetosphere of the earth and perhaps some measure of the scale size of the solar irregularities which caused their modulation. These cosmic ray measurements of total ionization, particle spectra, and to some extent, the x-ray measurements were the main series of experiments on Pocibo. Unfortunately, due to the difficulty with balloons, as will be described below, on the main Pocibo program only preliminary results were obtained with these instruments. However, a recent series of balloon flights in the Arctic in the spring of 1965 has provided good data, but with a much more limited set of objectives than the original Pocibo program. This will be described below in the "Little Pocibo" paragraphs.

II. POCIBO AND THE IQSY

The various scientific objectives of the Pocibo program were ideal for the period of solar minimum and provided the possibility of collecting data which could not be obtained with earth satellites. The U. S. National Committee for the IQSY approved this program as an official part of the U.S. effort, and invitations were made to other experimental groups to participate in the program. This might be done by providing experiments to put into the payload which could then be powered by the common battery supply, and the results telemetered back to the various groups who were participating. Also, the participation might involve cooperation in the launch sites of the balloons and the general idea was one of attempting to make the program a real international program of scientific cooperation in the most ideal sense. The program was described in the U.S. and International IQSY publications and was discussed at the IQSY Meeting in Rome in 1963. Considerable interest was aroused in various groups; however, the project failed to achieve cooperation between the Western countries and the Soviet Bloc nations and could not be officially endorsed by the Rome IQSY meeting. These questions were discussed on other occasions with various international groups including representatives of the Soviet Union, but no agreement was ever reached on the conduct of balloon flights of this kind, and no general agreement on the use of air space of the nations having territory in the polar regions was achieved. However, a resolution endorsing the Pocibo program for the IQSY was passed at a meeting of the COSPAR.

The winter operation of Pocibo in January, February and March, 1964 was conducted from Barrow, Alaska, but precautions had to be taken so that the balloons would not fly out of the territorial boundaries of Alaska. The only reason for attempting the operation at all under these circumstances, since it was obviously impossible to carry out the original objectives with this restriction, was that there were many unsolved technical problems with the launching, the telemetry, the payload, the balloon controls and the balloon vehicle itself. Major problems with the balloons and some other items prevented success with any of the Barrow flights, and the question of overflight over other countries never arose. Previously, permission had been sought to launch the IQSY Pocibo program from Danish territory at Thule, Greenland Airbase, but this permission was refused by the Danish government. An agreement was reached with the Norwegian government through its Space Commission to conduct launchings from northern Norway in the summer of 1964 under conditions such that the balloons would drift to the west across the Atlantic from Norway. By this time, an agreement had been made with Canadian government for the Pocibo balloons to pass over northern Canada. Again, balloon failures prevented realization of these summer flights and gave no chance to test the tracking of balloons over large distances. Quite a number of inquires continue to be made by persons interested in the project as a result of the IQSY meetings, but the major difficulties with the balloons floating in the air-space of unfriendly countries provides a major stumbling block for the ultimate success of this effort.

During the Norway operation in the summer of 1964 the University of Bergen, Norway and Litton Industries in Minneapolis, Minnesota provided experiments which were flown. These were developed by Dr. Harald Trefall of Bergen and Dr. Runke of Litton.

III. MAJOR TECHNICAL PROBLEMS

A. Balloons

At the beginning of this project, the art of building large plastic balloons had been in existence for 15 years. It was considered that the design and construction of a suitable balloon to lift the Pocibo payload of weight between 400 and 600 lbs. was a technical problem that was more or less solved. The actual experience, however, showed that the persistent problem of balloon failures was still present, and out of the eight launching attempts with full scale Pocibo payloads, only one flew successfully.

One of the unknowns in designing a balloon was the effect of launch shocks on the polyethylene at low temperature in the Arctic. However, except for this unknown quantity, it was expected that standard design procedures would lead to a satisfactory vehicle. By agreement between Raven Industries and the University of Minnesota, the design adopted was a polyethylene balloon of one mil thickness made over the tailored tapeless natural shape design. This design was originated in balloon studies made at the University of Minnesota and has been widely used in the industry. The natural shape configuration has cylindrical end sections sufficiently large in diameter so that when gathered to the top and bottom fittings, enough plastic was present to support the load. The balloon was equipped with a full duct appendix so that it would not take air even when settling from a ceiling altitude of 8 millibars to a ballast floor of 30 millibars. The guaranteed exclusion of the air can be achieved by attaching the duct appendix above the zero pressure point for lowest floating level, and is necessary for long flights where the balloon is not to lose altitude due to the intake of air and subsequent mixing with the balloon gas. The balloon was designed for a payload of 600 lbs. and had a volume of 1.5 million cubic feet. A flight train schematic is shown in Figure 1. Actually, the balloons flown on Pocibo flights 1 and 2 at Fort Churchill in the summer of 1963 were of preliminary design of somewhat thinner material and designed for somewhat lighter loads. It was one of these balloons, however, that gave an excellent flight (Pocibo 2) and showed some interesting I. R. radiation effects on the balloon behavior. (See Sec. IV). The other Churchill flight

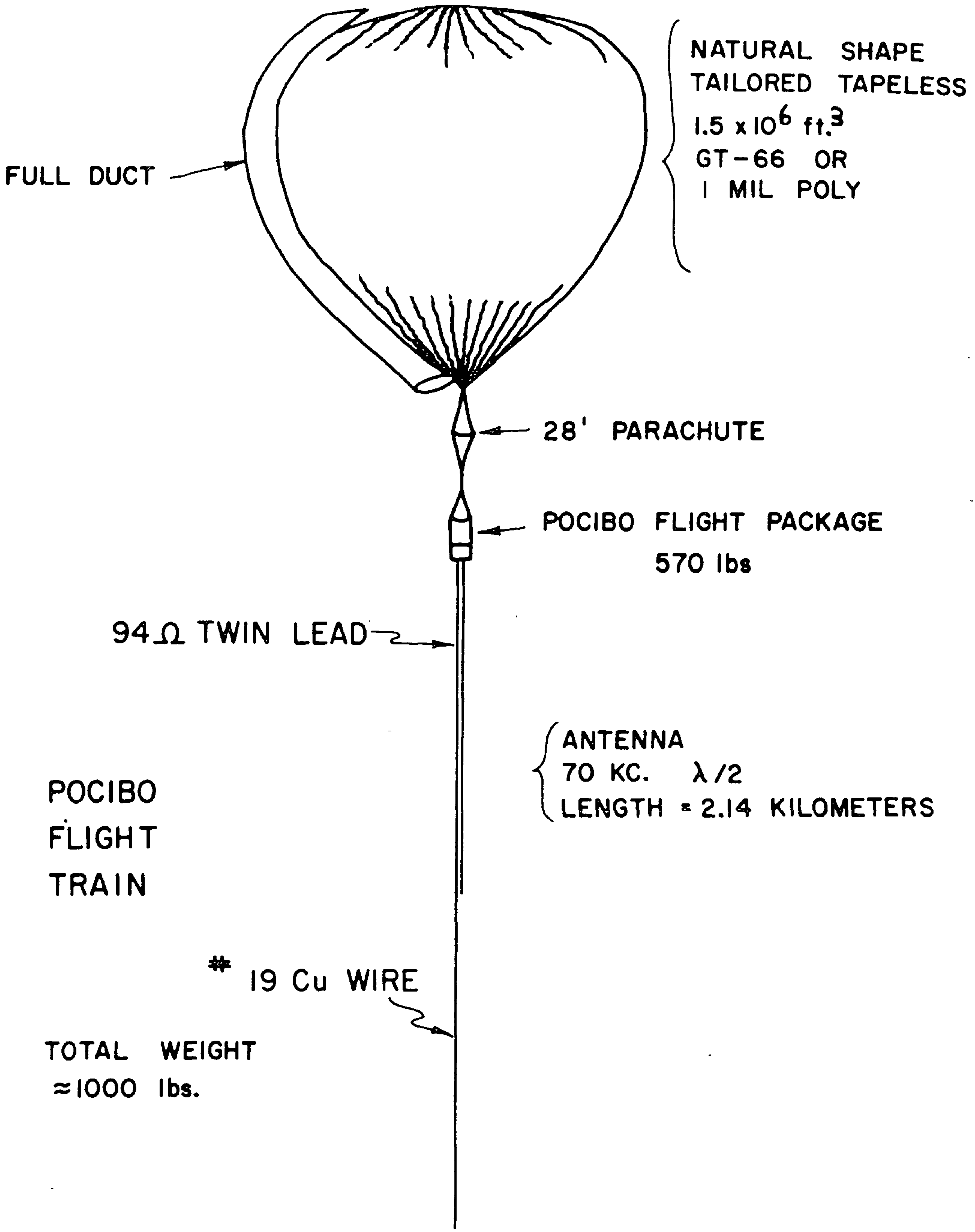
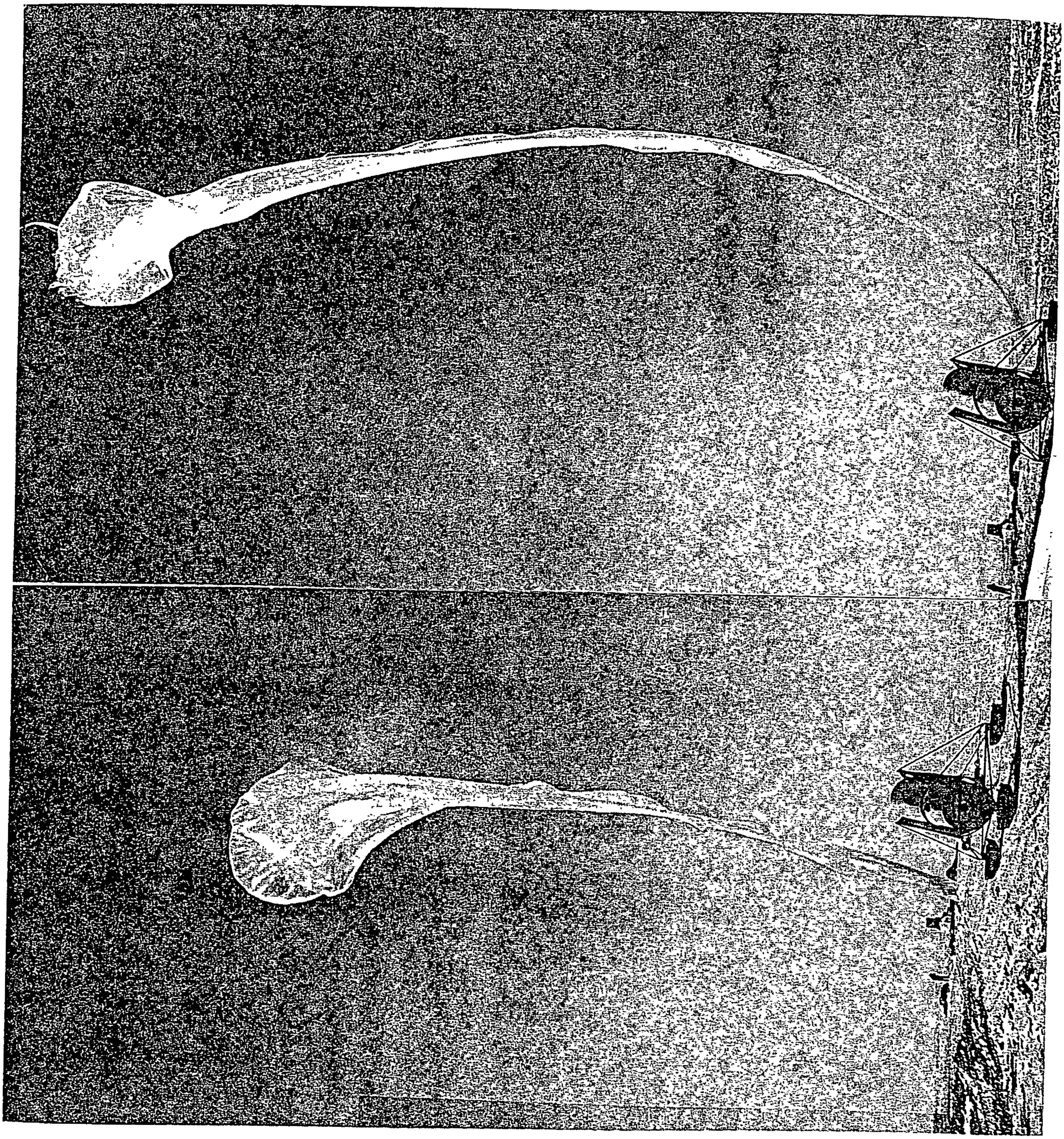
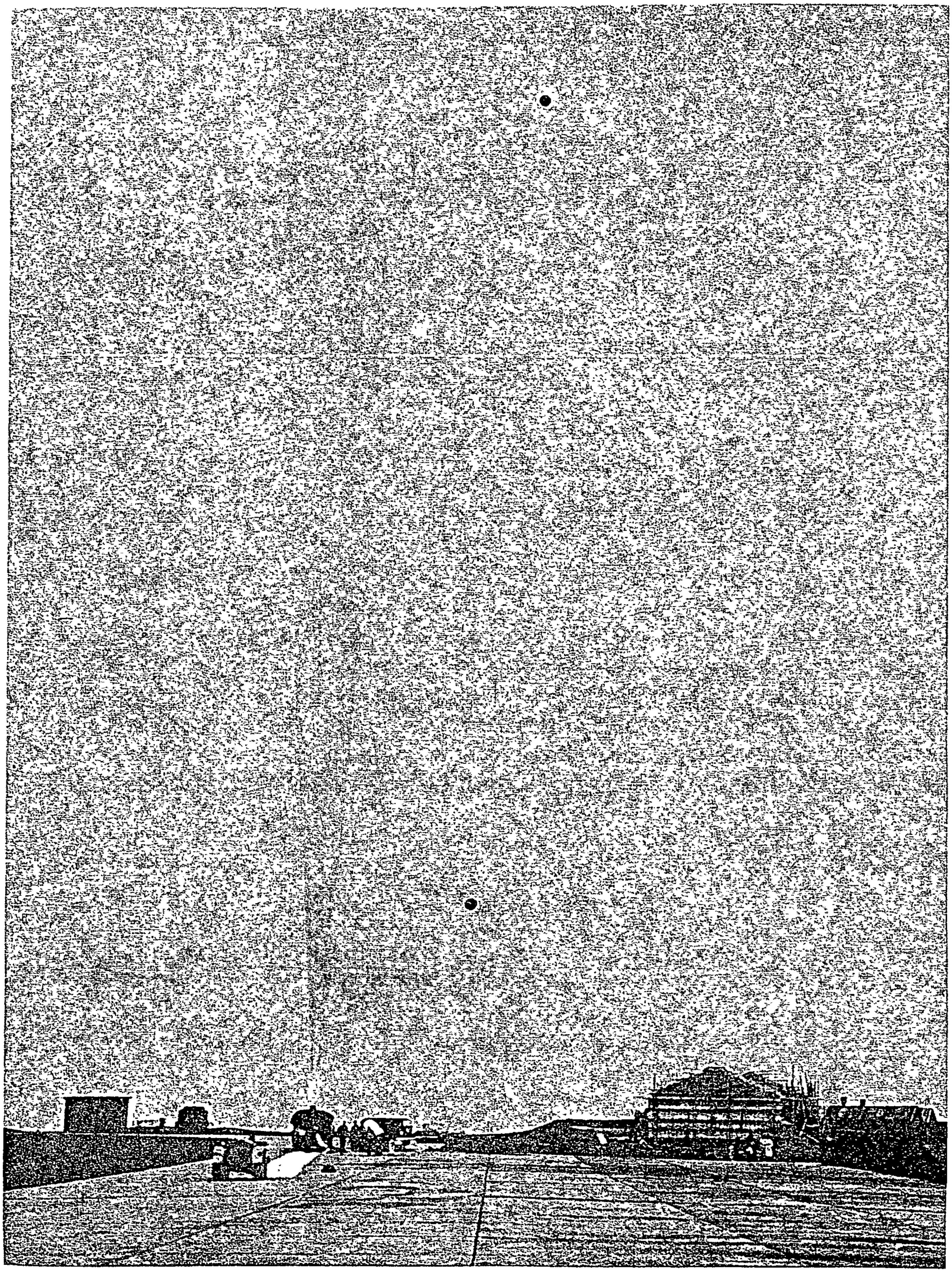

NATURAL SHAPE
TAILORED TAPELESS
1.5 x 10^6 ft.^3
GT-66 OR
1 MIL POLY
FULL DUCT
28' PARACHUTE
POCIBO FLIGHT PACKAGE
570 lbs
94Ω TWIN LEAD
ANTENNA
70 KC. λ/2
LENGTH = 2.14 KILOMETERS
POCIBO
FLIGHT
TRAIN
# 19 Cu WIRE
TOTAL WEIGHT
≈1000 lbs.

Figure 1

failed at ceiling and came back to the ground immediately (Pocibo 1). The details of the polyethylene balloons ordered for the remainder of the program are shown in the accompanying balloon specification sheet, Table I. These balloons were manufactured of inspected material, were made with great care and no manufacturing defects as such were found during use. Five of the six balloons purchased were launched. None of them flew successfully and the failures covered a variety of different types. The first of these balloons flown was Pocibo 3 launched from Point Barrow, 3 March 1964 and burst at ceiling evidently from a valving problem. Pocibo 4, flown from Point Barrow, Alaska on 6 March 1964 developed a leak which may have occurred during launch. This balloon leveled off at about one hundred millibars and eventually returned to the ground after six hours. The next balloon burst on launch release. This launch is shown in Figure 2. The launch sled and a Pocibo payload can be seen in these photos. The other two polyethylene balloons were flown from Andøya Airfield, Norway on flights 7 and 8. Both of these, in order to avoid any damage at launch, were launched vertically; that is, the balloon was inflated using the conventional launch spool technique to the required lift by metering, then the balloon was rolled up through the spool, transferred by a winch to the gondola and launched by cutting the anchor line. The entire assembly then took off in the vertical configuration in a smooth and very gentle manner. Absolutely calm winds were, of course, needed for this and occurred on two occasions at Andøya Airfield. However, despite the good launch, one of these balloons burst at ceiling, evidently encountering a valving failure. The other one burst at the tropopause. One of these launches is shown in Figure 3. The failures with these one mil polyethelene balloons were of various types associated with the deployment of the fabric on ascent or the stresses developed during



Photographs by Ted Spiegel courtesy of the National Geographic Society.



valving or launching. One must conclude that the 1 mil material is not sufficiently strong and that the design is inadequate in many respects to handle the 1,000 lbs. of lift normally in the bubble. In the case of flights 7 and 8, it was shown that the metered inflation gave the correct weigh-off as read on a dynamometer, and that therefore, the balloons did not leak. Furthermore, they were airborne very gently in the vertical launch without launch shock. These experiences showed that the failures must be attributed to inherent problems in the design of the balloon for payload weights of the Pocibo magnitude, with the tailored tapeless natural shape configuration.

In preparation for the Norway field trip, three balloons of another type were procured from the G. T. Schjeldahl Company. These were of similar size to the polyethylene balloons and were constructed of light weight mylar scrim material developed by Schjeldahl (see specification sheet, Table II). The balloons were very strong, and the layout and inflation at the Andøya Airfield encountered no difficulties. However, Pocibo 5, the first flight to be airborne, rose about one mile and leveled off and eventually settled into the ocean. This flight did not attain sufficient altitude to release the telemetry antenna. The second flight, Pocibo 6, when released from the launch spool picked up the payload momentarily to a height of 10 ft. and settled back to the ground. It now became apparent that there was a serious leak problem. The third balloon was hangar tested and it was found that these lightweight mylar scrim balloons were porous and lost gas at a rate of about 10% per hour. This loss rate easily accounted for the large loss of lift observed on flights 5 and 6. The cause of this failure was determined later by the Schjeldahl Company to be due to the bonding adhesive between the scrim and the mylar layer sticking over onto the next layer on the spool of material,so that when the material was unwound, tiny breaks were produced in the mylar. These breaks could be found by microscopic investigation. The stickiness was reportedly apparent when the material was unrolled to fabricate the balloon as the layers could be observed to cling together and break away with slight crackling noises.

A mylar balloon during inflation in Norway is shown in Figure 4. The leakage curve for an identical balloon during a hangar inflation test is shown in Figure 5. The portion inflated in the hangar was approximately that shown during an actual inflation in Figure 4.

Since the balloon failures prevented any real scientific success with the project, they constituted a major catastrophy. The problems were discussed with the manufacturers and with various other people, and it was apparent that balloon difficulties at this time were common throughout the industry.

Detailed reports on the leakage problem in the mylar balloons have been forwarded to the National Science Foundation, and to the balloon industry. Unfortunately, in the case of the polyethylene balloons, the exact causes of failure remain unproven.

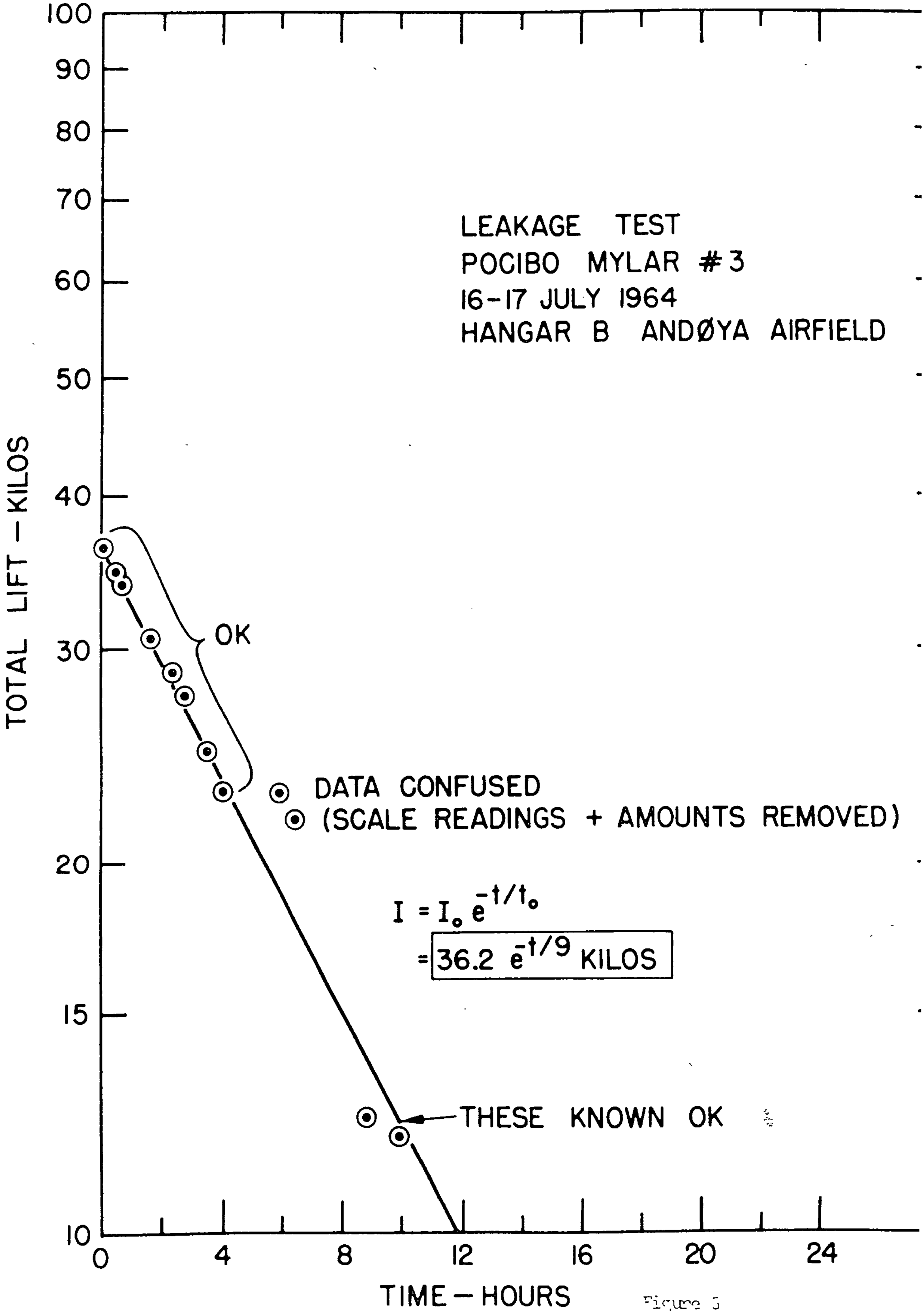

LEAKAGE TEST
POCIBO MYLAR #3
16-17 JULY 1964
HANGAR B ANDØYA AIRFIELD
OK
DATA CONFUSED
(SCALE READINGS + AMOUNTS REMOVED)
$I = I_o e^{-t/t_o}$
$= \boxed{36.2\ e^{-t/9}\ \text{KILOS}}$
THESE KNOWN OK
TOTAL LIFT — KILOS
100
90
80
70
60
50
40
30
20
15
10
0
4
8
12
16
20
24
TIME — HOURS

Figure 5

TABLE I

POCIBO BALLOON SPECIFICATIONS

Polyethylene Balloons Manufactured by Raven Industries, Inc.

Type of Balloon: Natural shape, tailored tapeless construction with full duct appendix. Cylindrical top and bottom sections to support load with proper safety factor. Raven Balloon Type 2333-351-5157.

Diameter: 157.6 ft.

Gore Length: 220.5 ft.

Volume: 1,500,000 cu. ft.

Number of Gores: 59

Design Σ: 0.25 at 330 lb. load.

Flying Σ: 0.18 at 550 lb. load.

Inflation Tube: 15 inch layflat 2.5 mil polyethylene, 90 ft. long, 190 ft. along gore from base.

Appendix: Full duct attached 120 inch layflat. Length 190 ft., 10 inches.

Base End Fitting: 1/2 inch eyebolt and spool banded to balloon with two 3/4 inch wide wraps.

Top End Fitting: Spool with two banding wraps similar to base fitting.

Balloon thoroughly corn-starched. Designed for 600 lb. payload. Constructed of 1.0 mil polyethylene. Approximate weight - 380 lbs.

Number Procured: 6

TABLE II

POCIBO BALLOON SPECIFICATIONS

Mylar Scrim Balloons Manufactured by G. T. Schjeldahl Company.

Type of Balloon: Natural shape with full duct appendix.
Schjeldahl Model Number GTS S-55.

Diameter, Gore Length and Volume: Same as Raven balloon.

Inflation Tube: 160 ft. long.

Appendix: Attached duct enters balloon 115 ft. from base.

Top and Bottom End Fittings: Double banded.

Constructed of 0.25 mil mylar with attached scrim webbing, single layer construction. Approximate weight 240 lbs.

Number Procured: 3

B. Long Range Radio Tracking and Communication.

1. General Consideration.

For many years, there has been a need for a long range communication system suitable for recovering scientific data from high altitude balloons. This need arises because of the drift of the balloon away from line-of-sight tracking stations and the subsequent rather short flights one gets in the wintertime high wind conditions. Even in summertime, flights are usually limited to 15 or 20 hours if only line-of-sight range is used from launch locations over northern U. S. or Canada. Inspection of the 10 mb polar maps constructed during the IGY by the Stratospheric Research Group, U. S. Weather Bureau, (Dr. Sid Teweles), showed that balloons launched from very northerly points such as Thule, Greenland; Barrow, Alaska; northern Norway or Resolute Bay, Canada, would drift so that they would remain within 3000 miles of these locations. The real problem was to find a system which would give tracking accuracy suitable for meteorological trajectory purposes, and at the same time be able to transmit the scientific data on cosmic radiation and other parameters from the payload. The propagation characteristics of various frequencies, particularly at sunspot minimum conditions, were investigated. It was decided that if a line-of-sight VLF system was used, the number of tracking stations would be prohibitively large and even then the tracking could only be accomplished across part of the Polar region. The direction finding problem at the LF range above 1 megacycle seemed to make this region also unsuitable for tracking purposes although it would be possible to use such frequencies for telemetry transmission. During some preliminary work in the summer of 1962 at Fort Churchill, Mr. Peter Hoff of the Defense Research Northern Laboratory suggested the use of a VLF frequency because of the much smaller polarization sky wave error and the lack of solar ionospheric day-night influence. With VLF frequencies, one achieves good 24 hour per day propagation over very long ranges. It was expected that during the winter night the spheric level, which is one of the problems of this frequency range, would be low in the Arctic. The difficulty with the VLF frequency range is the size of antenna needed for efficient radiation. With very low frequency ground base transmitters, extremely large amounts of power are needed because of the low antenna efficiency, since it is essentially impossible to get a resonant antenna From t balloon, however, flating at high altitude, it seemed possible to provide a half wave dipole if the VLF frequency was not too low. It was decided to compromise on a frequency of around 70 kc which meant that the half wave radiator would be 2.14 km in length. The type of radiator chosen was the free space dipole similar to that developed for higher frequencies on the University of Minnesota balloon project in 1954. With this radiator the transmitter is located at one end of the antenna, which consists of a sectio of twin lead half the length of the antenna and a single lead for the other half. In effect, this antenna is a center fed half wave dipole in which one leg of the antenna is combined with the transmission line so that the transmitter can be located in the balloon and the entire antenna trailed down be Work was begun on the problem of deploying a length of wire approximatly a mile and a half long and after many trials including even some preliminary Pocibo type flights at Churchill with winches and various devices, a yo-yo spool was devised by Mr. Rudolph Thorness of the Physics Department, Univer of Minnesota. This yo-yo spool contained the entire antenna wound up betwe the two aluminum spinnings which constituted the yo-yo. It was dropped fro the balloon and unwound freely trailing the wire out behind. The yo-yo is gyroscopically stable and aerodynamically streamlined and falls rapidly, achieving a spin velocity of up to 10,000 rpm and a linear speed of several hundred miles per hour near the end of the drop. At the end of the drop, the spool leaves the wire and falls to the ground. The drop must be conducted over remote areas and this precaution was observed on the flights. Many difficulties were encountered in the development of this system, but once the technique of winding the wire and constructing the spool was achieved the drops became very reliable. No failures on the main Pocibo program were encountered from the yo-yo antenna drop. About 20 helicopter ascents were used.

With the antenna problem and deployment problem solved, a 10 watt crystal controlled telemetry transmitter was constructed and a suitable digital data system devised with a bit rate of either 16 bits per second or 32 bits per second. This digital data system achieved the maximum information rate for the band width used and employed the Manchester type bi-phase modulation which has been used for satellite and space probes. Reception of the signal was simple and could be done with ordinary tape recording equipment. The telemetry tapes were fed through a signal conditioner for automatic computer analysis. This digital system has been completely worked out and is one of the major technical achievements of this program. It is described in detail below in the "Airborne System" and "Ground Station" sections.

Due to the balloon failures, no adequate opportunity for testing the long range capability of the overall system was obtained. However, one of the flights at Barrow was tracked for a considerable distance, although the balloon was not at ceiling altitude, from both the T-3 drifting tracking station and the station at Barrow. In general, it was found that the spheric levels in the Arctic winter were very low and that the noise background was more or less as expected. However, in the summertime in full sunlight in northern Norway, considerable spheric problems were encountered. The spherics w all connected with weather systems. At times, the spheric level was very low bu when storms moved in, the spheric levels became intolerably high. This was on the Andøya Airfield site at a latitude of 70° north.

It was decided to use loop antennas for reception because they could be turned to resonance and would, therefore, have a narrow bandwidth and high gain and the directional properties would reduce the noise by confining it to directions towards and away from the balloon. Details of the loops follow below. Two crossed loops were used, one with its plane directly toward the balloon and another one at right angles to null the signal. The telemetry signal from the maximum signal loop was then compared in phase and amplitude with that from the null loop by a cross-correlating device and the resultant signal used to drive a servo which turned the loops. In the initial stages of the project in the spring of 1964 before this automatic system had been developed, single loops were used and were nulled by hand using an output meter on the receiver and a special technique for taking readings either side of minimum signal. It was hoped to achieve a directional bearing accuracy of less than 1 degree. The number of test cases were insufficient to establish whether such accuracy could be achieved. And, in fact, more than two DF stations are actually needed in order to check the accuracy. Since none of these conditions were really reached in the project, the ultimate capability of the direction finding idea has not been satisfactorily explored. A detailed discussion of the DF system is given in the section describing the ground station.

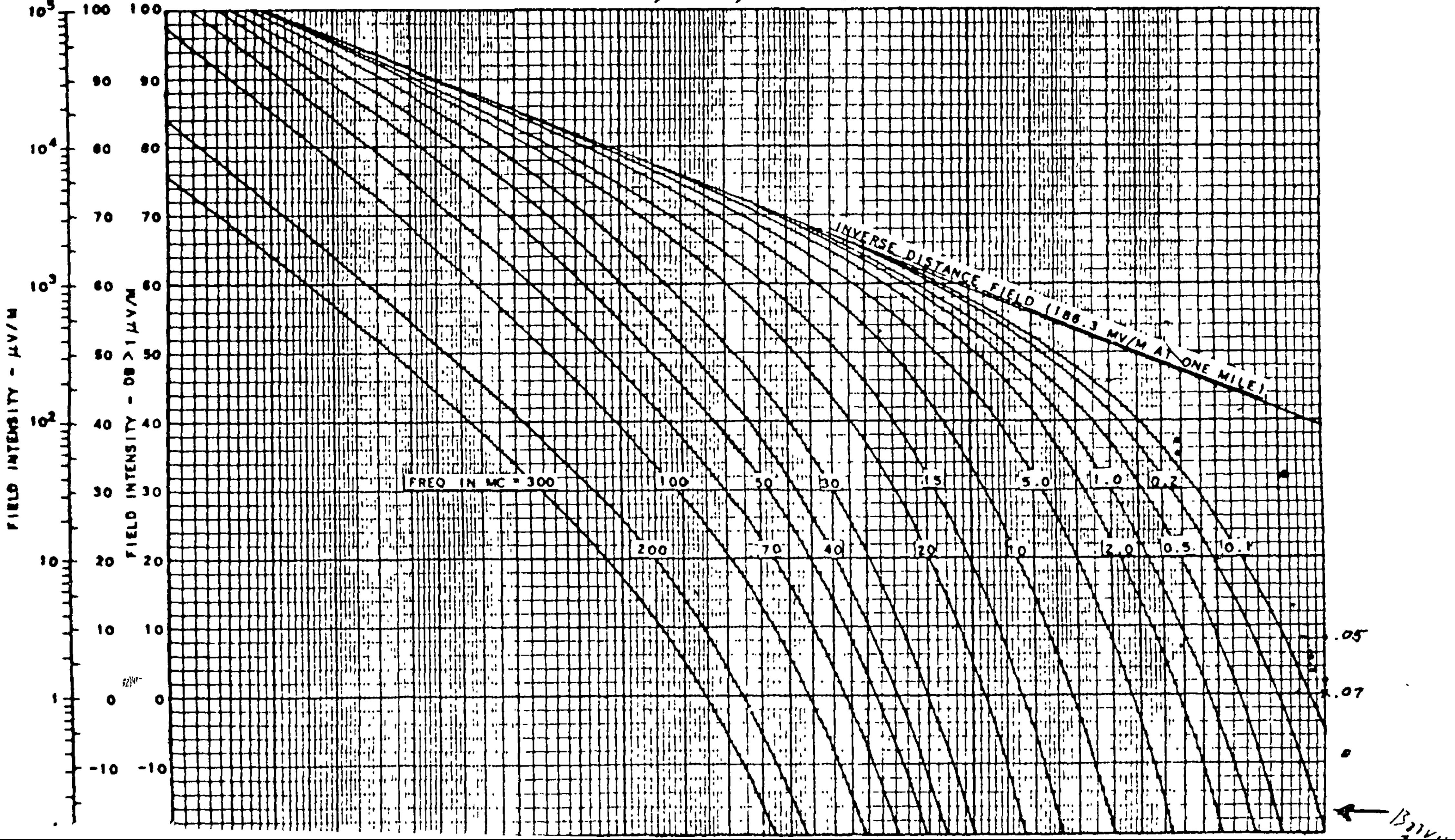
2. Limitations of Telemetry Range

The transmitter efficiency was extremely high and produced 10 watts peak power output. However, inevitable losses occurred in the very long dipole antenna so that the effective peak power transmitted from the space antenna was 3 watts. The average power transmitted was 1.5 watts. Considering the duty cycle of the digital keying, at a range of 1000 miles in a lossless medium, the signal strength from the transmitter should be 7 μv/meter. However, the transmitting medium always contributes some absorption so the expected signal will be much lower. Observations relating to the attenuation of radio signals in the 70 kc range were made on fixed teletype stations transmitting from Thule, Greenland and Halifax, Nova Scotia and received at Barrow, Alaska in the Pocibo ground station. The transmitting power was assumed to be 10% of the antenna input power given in the International Log for the stations measured and the observed signal strength was noted at the receiving station. The average signal strengths were close to the theoretically computed ground wave intensities as shown in Figure 6.

The receiving antenna was an electrostatically shielded loop of 20 turns with an area of two square meters and an impedance of 200 ohms into the receiver. The VLF receiver had a sensitivity of 0.018μv with a 200 ohm source for a zero db signal to noise ratio. The effective bandwidth of the receiver was 100 cycles per second. The information bandwidth was 32 cycles per second for the 32 bit per second rate. With the loop connected to the receiver, the overall sensitivity was 0.08 μv/meter. That is, a radio frequency signal with an electric field strength of 0.08 μv/meter would produce a signal at the input terminals of the receiver of 0.018 μv. However, the usable threshold of the system is considerably higher than this due to the real radiation noise in the atmosphere. Even in the absence of man-made local noise at Barrow, and

GROUND-WAVE FIELD INTENSITY AGAINST DISTANCE CURVES
FOR VARIOUS FREQUENCIES IN MEGACYCLES PER SECOND

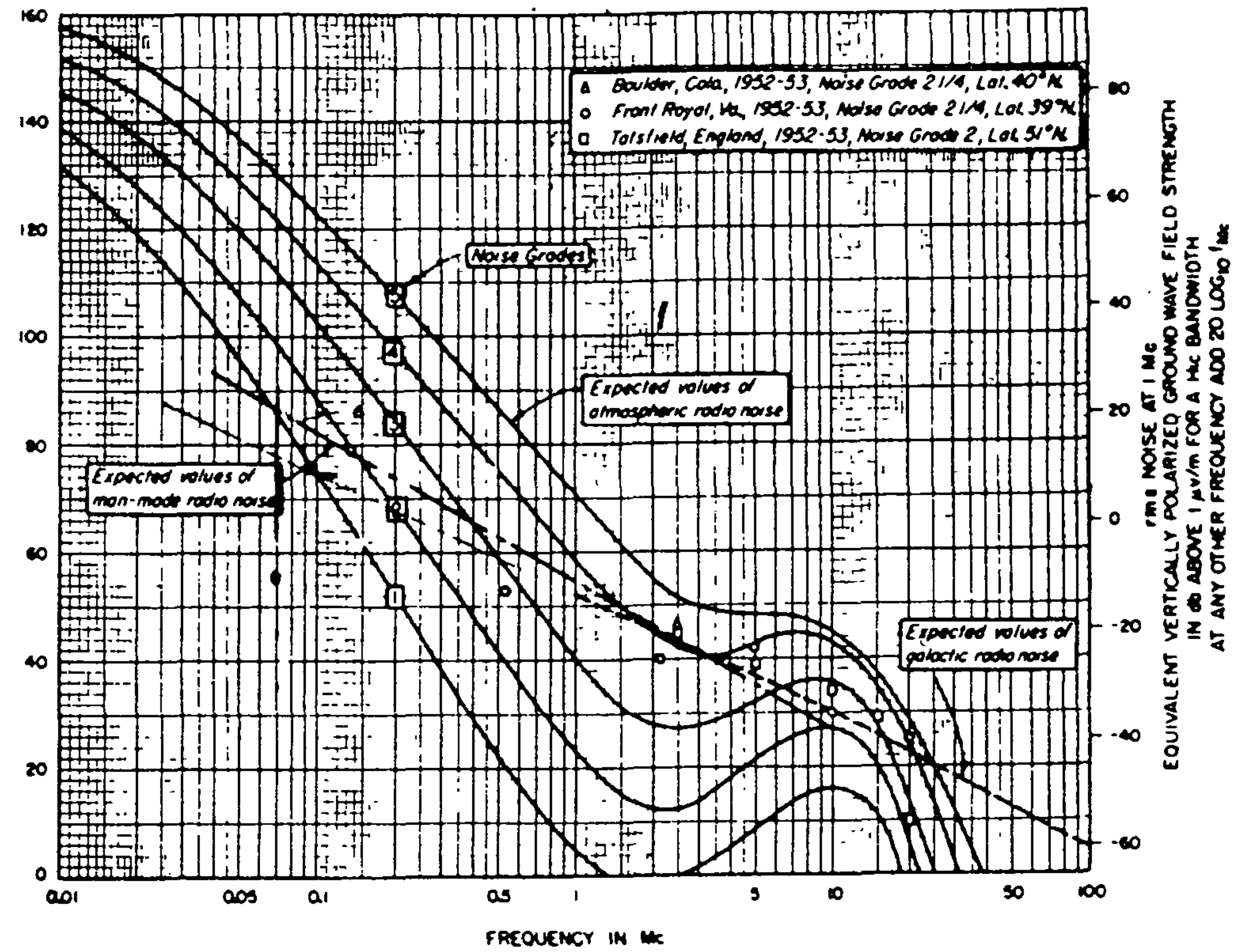
FOR
VERTICAL POLARIZATION
ANTENNAS AT THE EARTH'S SURFACE
TRANSMITTING ANTENNA INVERSE DISTANCE FIELD INTENSITY
OF 186.3 MILLIVOLTS PER METER AT ONE MILE
SEA WATER, $\epsilon = 80$, $\sigma = 5$ MHOS/M



spherics, which were very low at Barrow, the lowest noise level observed was 7 db above 0.08 μv/meter in the 100 cycles per second bandwidth of the receiver. Under these circumstances, the noise was all due to radio frequency radiation from the surrounding space, and the receiver and antenna were introducing no appreciable noise. Median values of radio noise to be expected are shown in Figure 7.

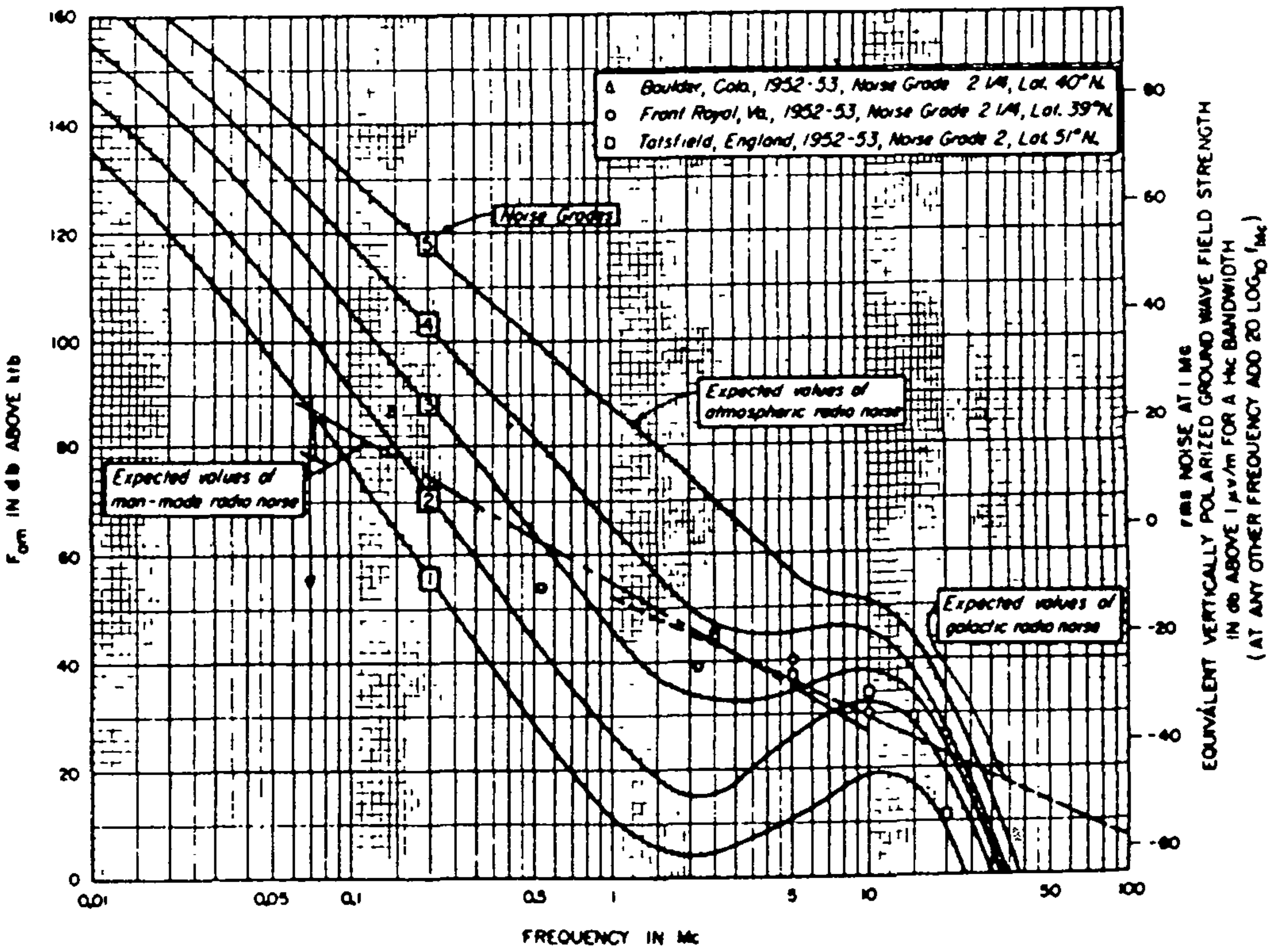
It is possible to determine the bit error probability for both the 16 and 32 bit per second rate, and this is shown in Figure 8, as a function of signal to noise ratio measured using the VLF receiver signal level meter. For example, for zero db signal to noise ratio in the receiver, the bit error probability is less than 0.01 for 16 bits per second, that is to say, the errors would be one bit in a hundred bits. Figure 8 and the considerations above apply to white type of spectral noise which is not always the type that is encountered, but they nevertheless give a figure of merit for the system.

By the observations that were made of fixed transmitters at known distances, it was found that the signal strength was near the computed ground wave intensity for the station as shown by the points in Figure 9, Since Figure 9 applies specifically to the balloon transmitter, whose average radiated power is 1.5 watts, the fixed transmitter points shown could only be plotted after scaling the observed signal strength measured in μv/meter by the factor $\left(\frac{1.5\text{ watts}}{10\%\text{ listed power}}\right)^{1/2}$. One can compute the minimum expected distance in order to achieve zero db signal to noise from the balloon transmitter by knowing the local radio frequency noise level. This result may be read from the lower curve in Figure 9. One would expect to be able to hear the balloon a minimum distance of 1600 miles from the Barrow station and still provide a zero db signal to noise ratio and a bit error of 0.01. Unfortunately, balloon flights of this distance were not achieved on the program. The longest range



Median values of radio noise expected for a short vertical antenna.

For the time block, 0800-1200, winter.



Median values of radio noise expected for a short vertical antenna.

For the time block, 1200-1600, winter

Figure 7

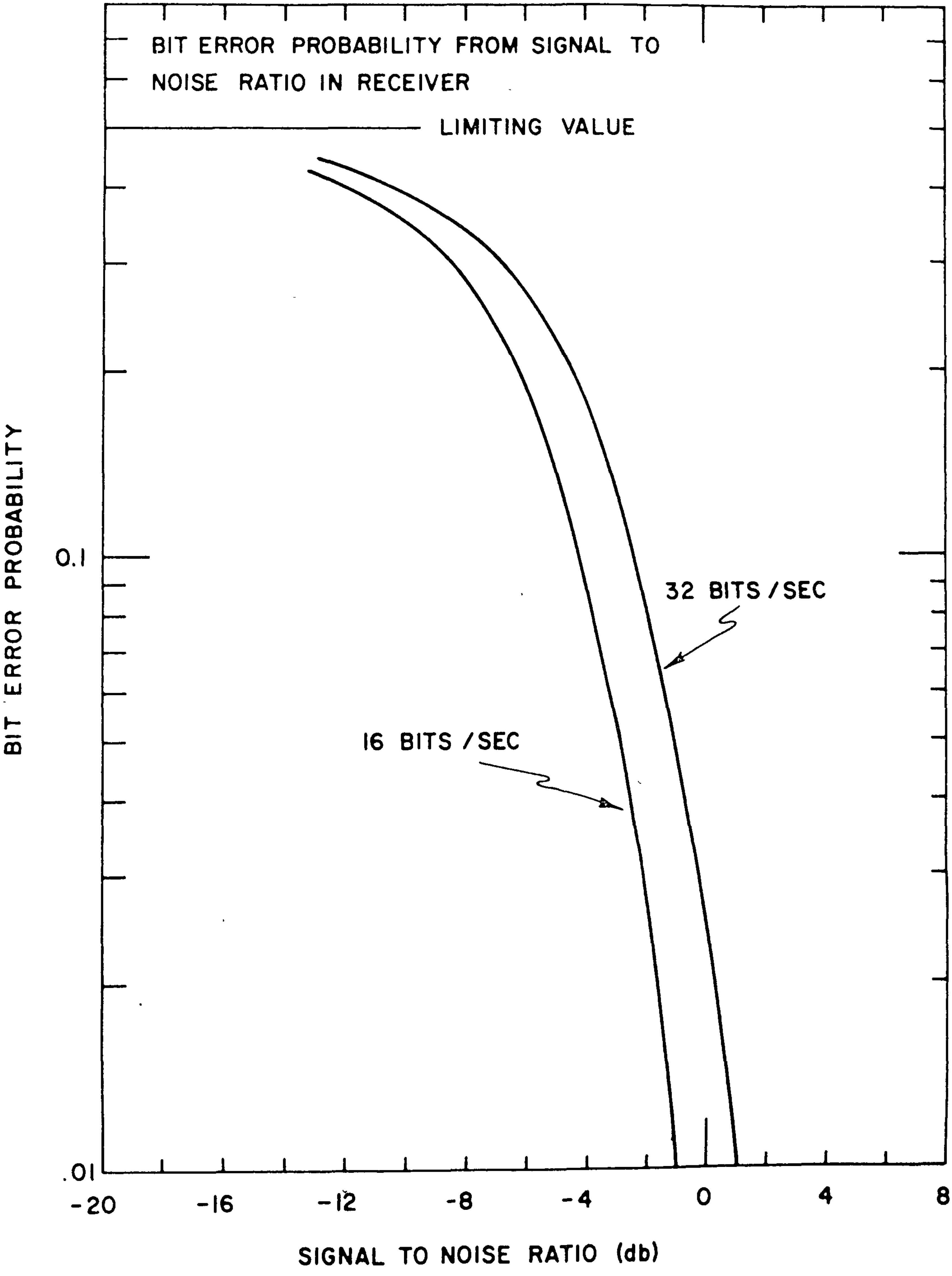

BIT ERROR PROBABILITY FROM SIGNAL TO NOISE RATIO IN RECEIVER
LIMITING VALUE
32 BITS / SEC
16 BITS / SEC
BIT ERROR PROBABILITY
0.1
.01
-20
-16
-12
-8
-4
0
4
8
SIGNAL TO NOISE RATIO (db)

Figure 8

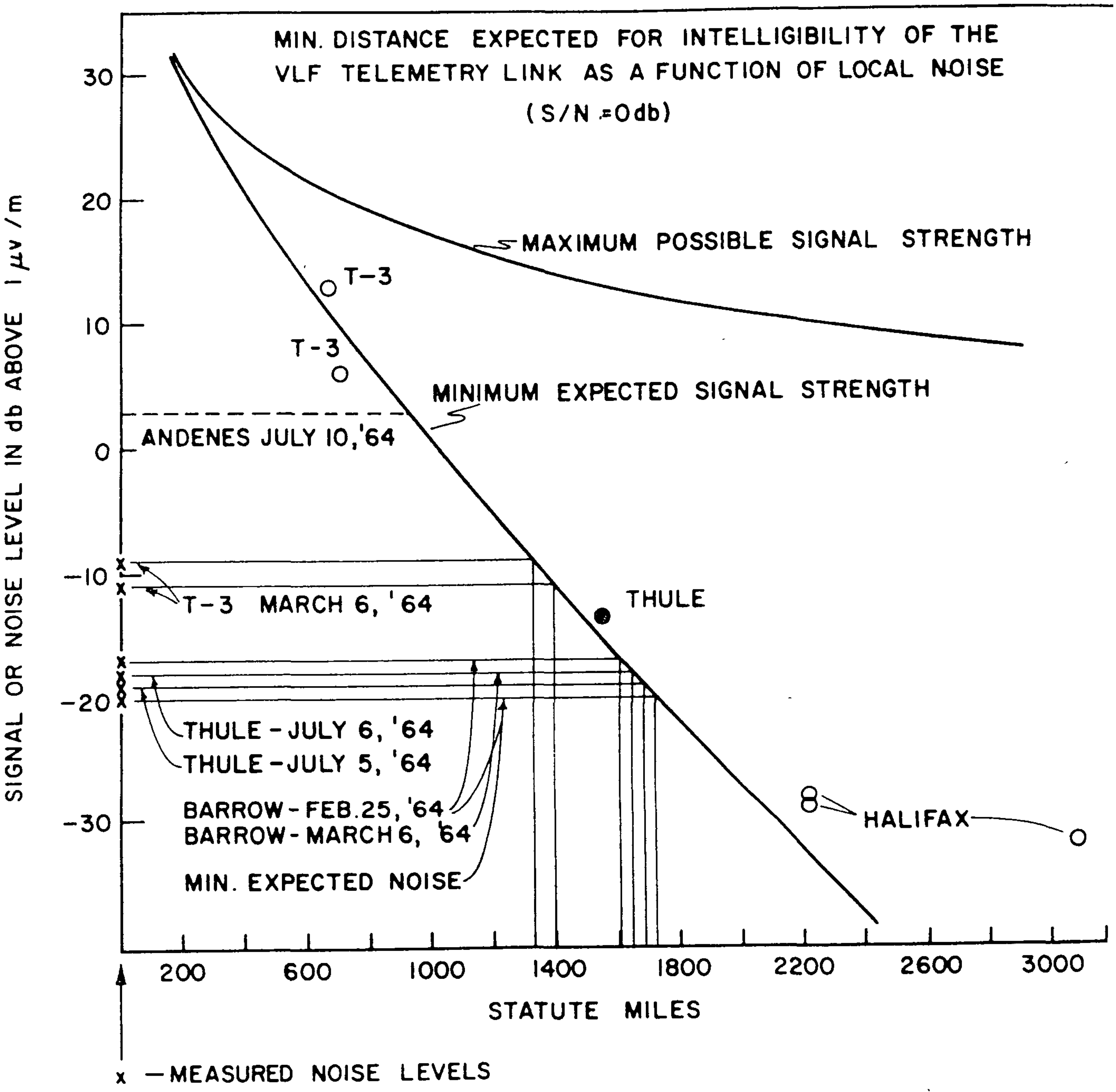

MIN. DISTANCE EXPECTED FOR INTELLIGIBILITY OF THE VLF TELEMETRY LINK AS A FUNCTION OF LOCAL NOISE
(S/N = 0db)
SIGNAL OR NOISE LEVEL IN db ABOVE 1 μv/m
30
20
10
0
-10
-20
-30
200
600
1000
1400
1800
2200
2600
3000
STATUTE MILES
MAXIMUM POSSIBLE SIGNAL STRENGTH
MINIMUM EXPECTED SIGNAL STRENGTH
T-3
T-3
ANDENES JULY 10, '64
T-3 MARCH 6, '64
THULE
THULE - JULY 6, '64
THULE - JULY 5, '64
BARROW - FEB. 25, '64
BARROW - MARCH 6, '64
MIN. EXPECTED NOISE
HALIFAX
x — MEASURED NOISE LEVELS

Figure 9

of telemetry was about 700 miles from the receiving site (shown in Figure 9 by T-3 points) so these calculations regarding the limits of range for balloon signals were not checked by direct observations. The maximum possible signal strength (upper, curve in Figure 9) results from the inverse square law applied to the known power radiated by the balloon.

C. The Airborne System

1. Package Design

The design of the flight package was achieved as follows: The desired altitude range of the flight was first established, then a balloon of approximately the right size was selected so that the weight of the balloon and the first estimate of the package weight would be compatible with the desired altitude range. Then the quantity of ballast to be carried was estimated (about 25% of gross) which was between 200 and 300 pounds. The other main weight item was the power supply and the antenna for the telemetry. Because of the long antenna, the weight of the wire with its dropper was 50 lbs. and could not be reduced below this figure. With the 70 kc telemetry system, 10 watts of power was to be generated, and therefore, this determined the battery size and it was decided to use silver cells to save weight and to provide good low temperature behavior and constancy of terminal voltage. This battery weighed about 40 lbs. With the principal heavy items of the system determined, a suitable framework was designed which could support the main weight of the payload during a rough launch, for example, if the payload dragged on the ground or bumped. It was designed so that the exterior of the package was strong enough to protect the instruments and to support the rather large ballast load without damage. This required a package which was cylindrical in shape, especially molded of fiberglass with strengthening rings, and a steel clamp band near the center which locked an aluminum equator plate on which the heavy parts of the payload were hung. This arrangement was tested by dropping the package on its side or lower edge from certain height and it was determined that the construction was sufficiently strong to withstand anticipated launch stresses. Launch difficulties were expected becaus of possible windy conditions in the Arctic, and in general, the difficult logistics of the Polar operation. The complete package with its complement of scientific instruments, ballast, battery container, antenna etc., and the parachute weighed from 500 - 600 lbs., depending upon the exact amount of ballast used. A cut-away view of the package is shown in Figure 10 and a scene prior to launch at Barrow in Figure 11. A view of the Pocibo III gondola with cover removed is shown in Figure 12.

The temperature environment for a one-week duration flight in the Pol night is a severe one, and the package had to be designed with rather good insulation because the amount of heat available from the payload was small. The package was constructed with a 1/8th inch thick fiberglass exterior line with polyurethane foam of low density. The bottom section of the package wa open and contained the ballasting device, the antenna drop mechanism, droppa radiation detectors and other items. The top two thirds of the package was thermally sealed and contained the power supply batteries, the telemetry system and the scientific instruments. All of these were mounted in an aluminum rack which was set on a polyurethane foam base 4.5 inches thick. The electrical leads were molded through this space and were the only connections through it so that thermal conductivity was kept as low as possible. The upper part of the package fitted over this base somewhat like a bell jar and was closed tightly to prevent thermal leakage and then clampe securely to the lower portion by a steel clamp band.

The gondola was environmentally checked in the walk-in chamber of Environ Inc. in Minneapolis on January 3, 1964. The results of this test

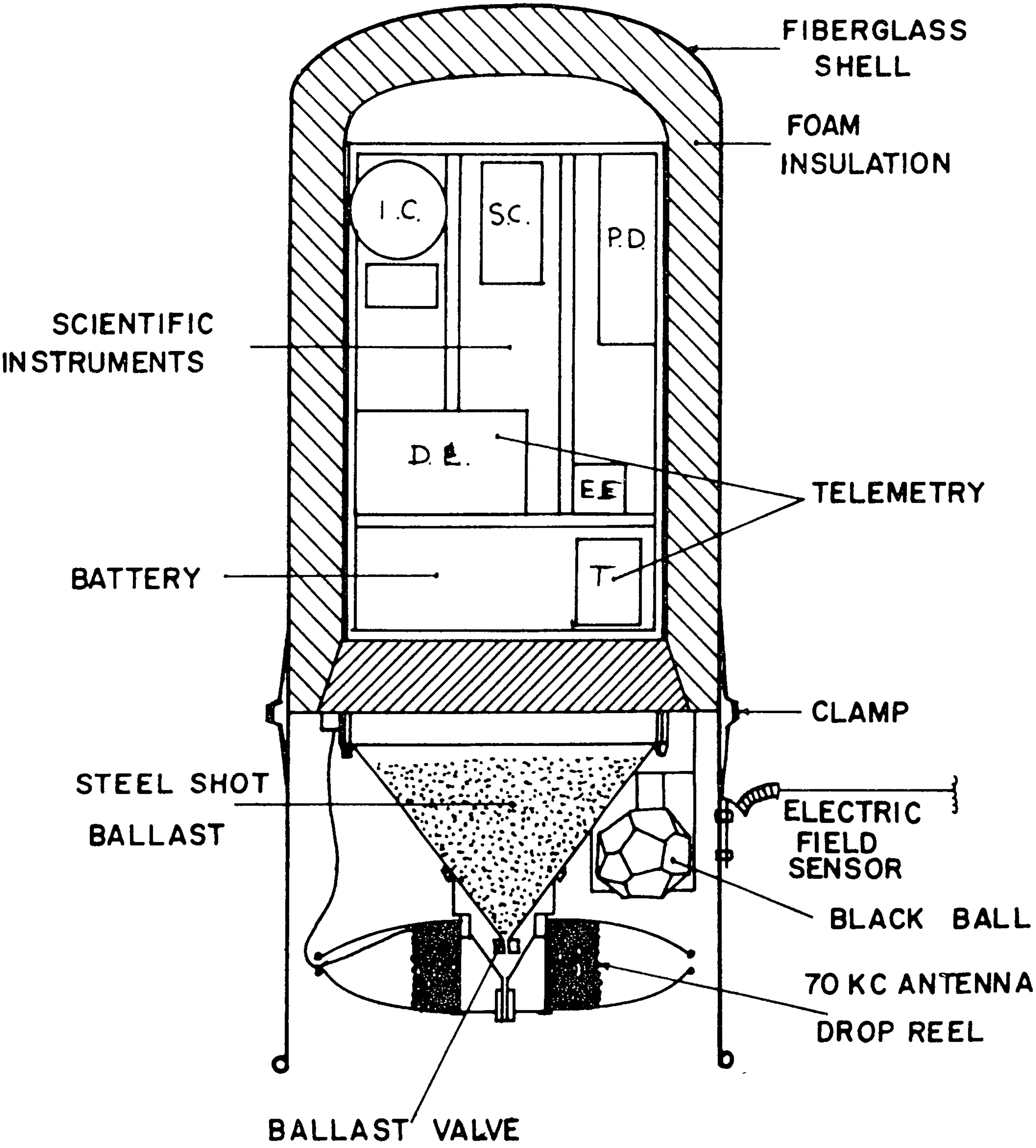
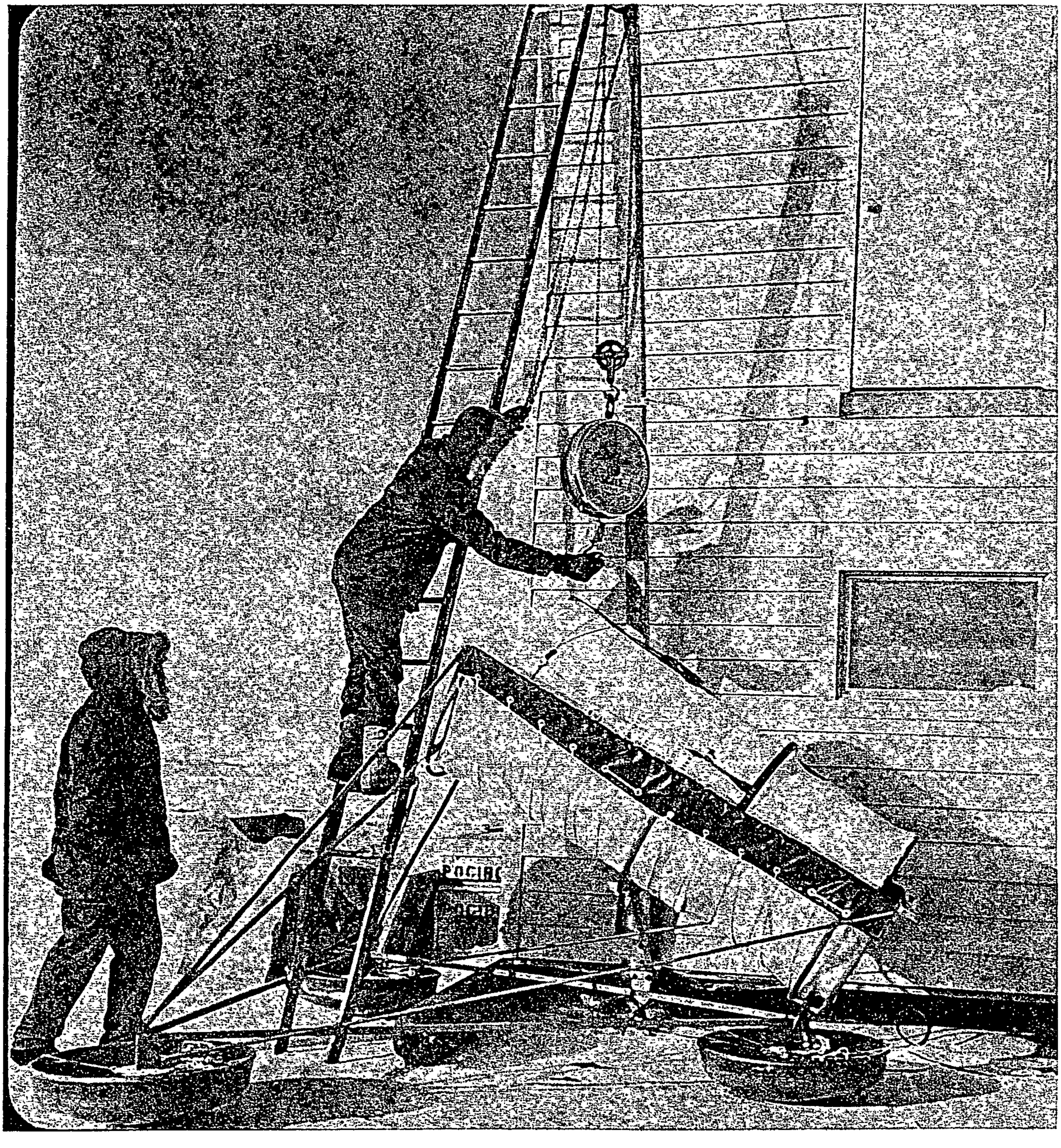
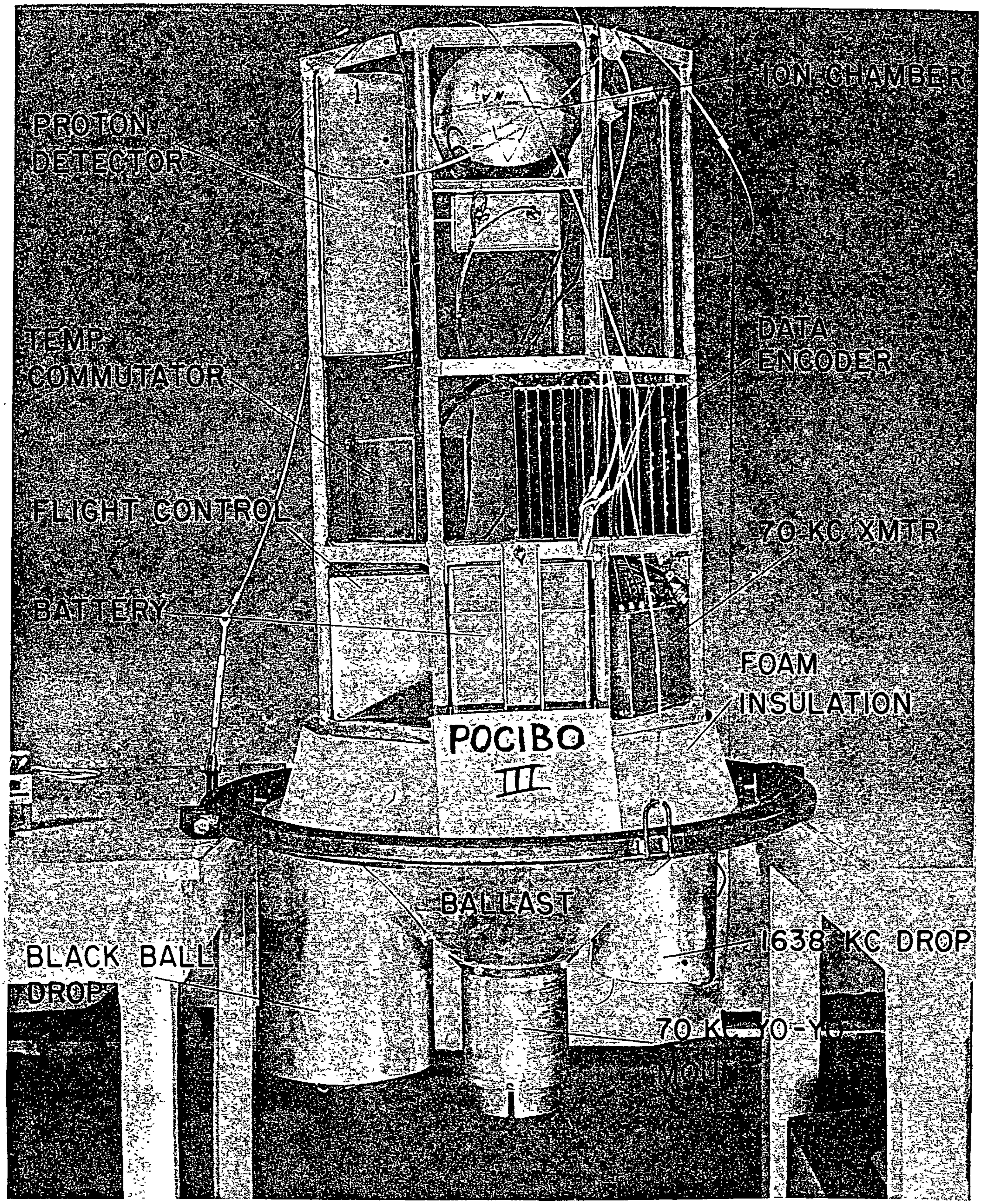

FIBERGLASS SHELL
FOAM INSULATION
I.C.
S.C.
P.D.
SCIENTIFIC INSTRUMENTS
D.E.
E.E.
TELEMETRY
T
BATTERY
CLAMP
STEEL SHOT BALLAST
ELECTRIC FIELD SENSOR
BLACK BALL
70 KC ANTENNA
DROP REEL
BALLAST VALVE

Figure 10




ION CHAMBER
PROTON DETECTOR
TEMP COMMUTATOR
DATA ENCODER
FLIGHT CONTROL
70 KC XMTR
BATTERY
FOAM INSULATION
POCIBO III
BALLAST
1638 KC DROP
BLACK BALL DROP
70 KC YO-YO
MOU

are shown in Figure 13. The inside of the gondola was heated with 10 watts power which was dissipated by a 100 ohm resistor. The test chamber was coo to -95° F with a jet of evaporating CO_2 before the power was switched on as shown in Figure 13. The temperature inside the gondola approached -64° F with a time constant of 4.3 hours. From the temperature time curves, both t total heat loss rate of the package and its heat capacity were evaluated. T heat loss was found to be 0.57 watts per degree centigrade temperature diffe ence, and the heat capacity of the package as tested empty to be equivalent 4.8 pounds of water. The exterior of the package was strongly ventilated during these tests.

Further environmental data was obtained on the Pocibo 4 flight from Barrow, Alaska on March 6, 1964. The temperatures were measured inside and outside of the package by the temperature cycler and the results from this flight are shown in Figure 14. In this particular flight, the balloon lost gas by leakage and leveled off near the tropopause with a very slow descent until parachute release. The flight equipment operated throughout the flight and telemetry records were obtained. If one takes the battery box temperature as characteristic of the inside of the gondola and uses the total power generated inside (6 watts) and the measurements made in the above described environmental test, one finds that the loaded gondola has an equivalent heat capacity of 35 pounds of water. This has to be determine from the cooling time constant of the inside of the package as shown during the five hours of flight time in Figure 14. However, the possibility that the loss by conductivity is different in the high atmosphere than in the test chamber must be considered and in fact a lower thermal conductivity could account for the higher apparent heat capacity. The thermal time constant for the flight gondola was 31 hours or longer. The lack of long flights prevented a complete study of the behavior of the package in the

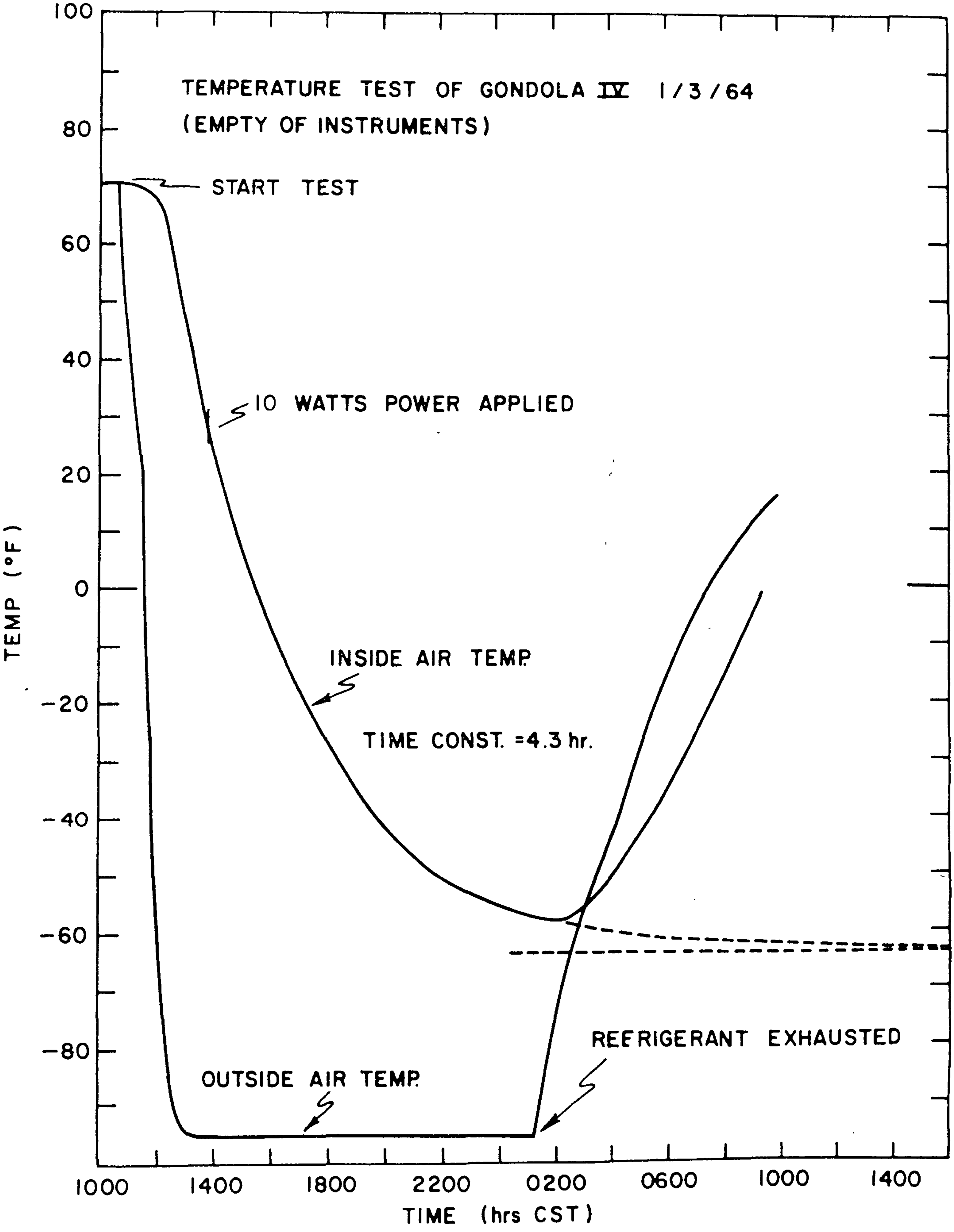
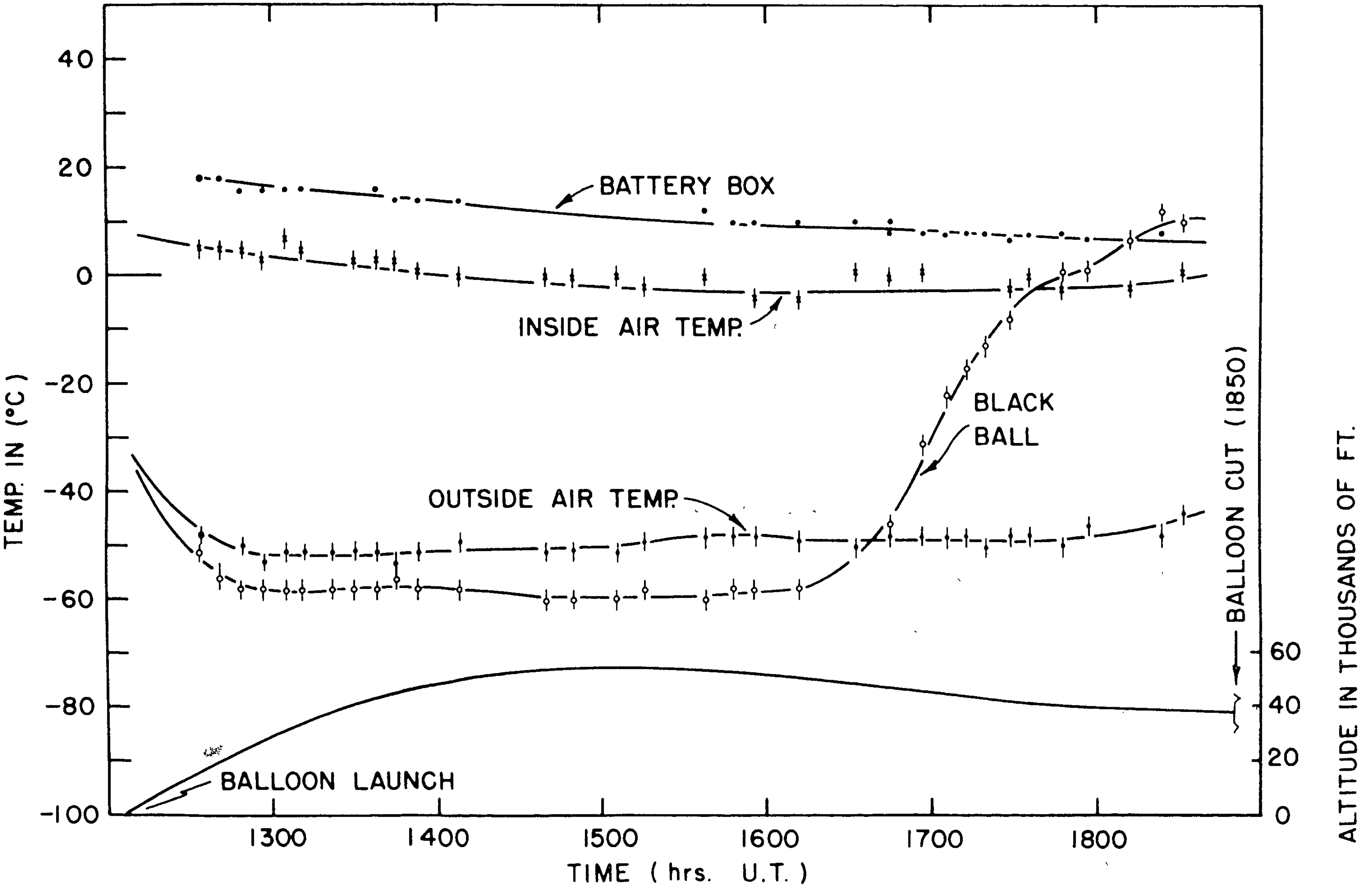

TEMPERATURE TEST OF GONDOLA IV 1/3/64
(EMPTY OF INSTRUMENTS)
START TEST
10 WATTS POWER APPLIED
INSIDE AIR TEMP.
TIME CONST. =4.3 hr.
REFRIGERANT EXHAUSTED
OUTSIDE AIR TEMP.
TEMP (°F)
100
80
60
40
20
0
-20
-40
-60
-80
TIME (hrs CST)
1000
1400
1800
2200
0200
0600
1000
1400

Figure 10


TEMP. IN (°C)
40
20
0
-20
-40
-60
-80
-100
BATTERY BOX
INSIDE AIR TEMP.
BLACK BALL
OUTSIDE AIR TEMP.
BALLOON LAUNCH
BALLOON CUT (1850)
1300
1400
1500
1600
1700
1800
TIME (hrs. U.T.)
ALTITUDE IN THOUSANDS OF FT.
60
40
20
0

polar environmental situation. In Figure 14, one sees the black-ball temperature rise from -60° up to +20° as the sun appeared above the horizon on March 6, 1964 over the lower fringes of the Arctic Ocean where the balloon was drifting. There is no sunrise effect on the other temperature channels.

2. Electronic Design - General.

The main features of the electronic design of the Pocibo package and their inter-relationships can be understood by the block diagram, Figure 15. This diagram is typical of the complement of instruments flown during the Norwegian operation in the summer of 1964. The scientific instruments in Figure 15 consist of the ion chamber and geiger counters as a unit, the x-ray scintillator, the electric field experiments, the α-tron pressure gauge, the proton detector and several additional experiments such as the temperature cycler for sensing the black-ball air temperature, interior package temperatures, etc. and the ozone experiment, these latter two not being shown in Figure 15. The Pocibo flight unit contained a flight control box which included the flight timers, aneroid instruments for terminating the flight if necessary and the ballast control system which used the α-tron pressure gauge as a sensor. The flight control box had outputs which would control the dropping of ballast and the firing of squibs. All of the necessary information outputs from the scientific experiments, the pressure gauge, the ballast sense wheel and other necessary bits of housekeeping information were fed into the binary storage registers which were sampled by the digital data system in sequence and modulated the 70 kc transmitter. The other main component was the battery power supply for the experiments, for the data encoder, and for the transmitter. The principal elements of this system are also shown in Figure 12 which shows the Pocibo III gondola flown at Barrow, Alaska in February, 1964. This report will not include details of the scientific instruments for collecting cosmic

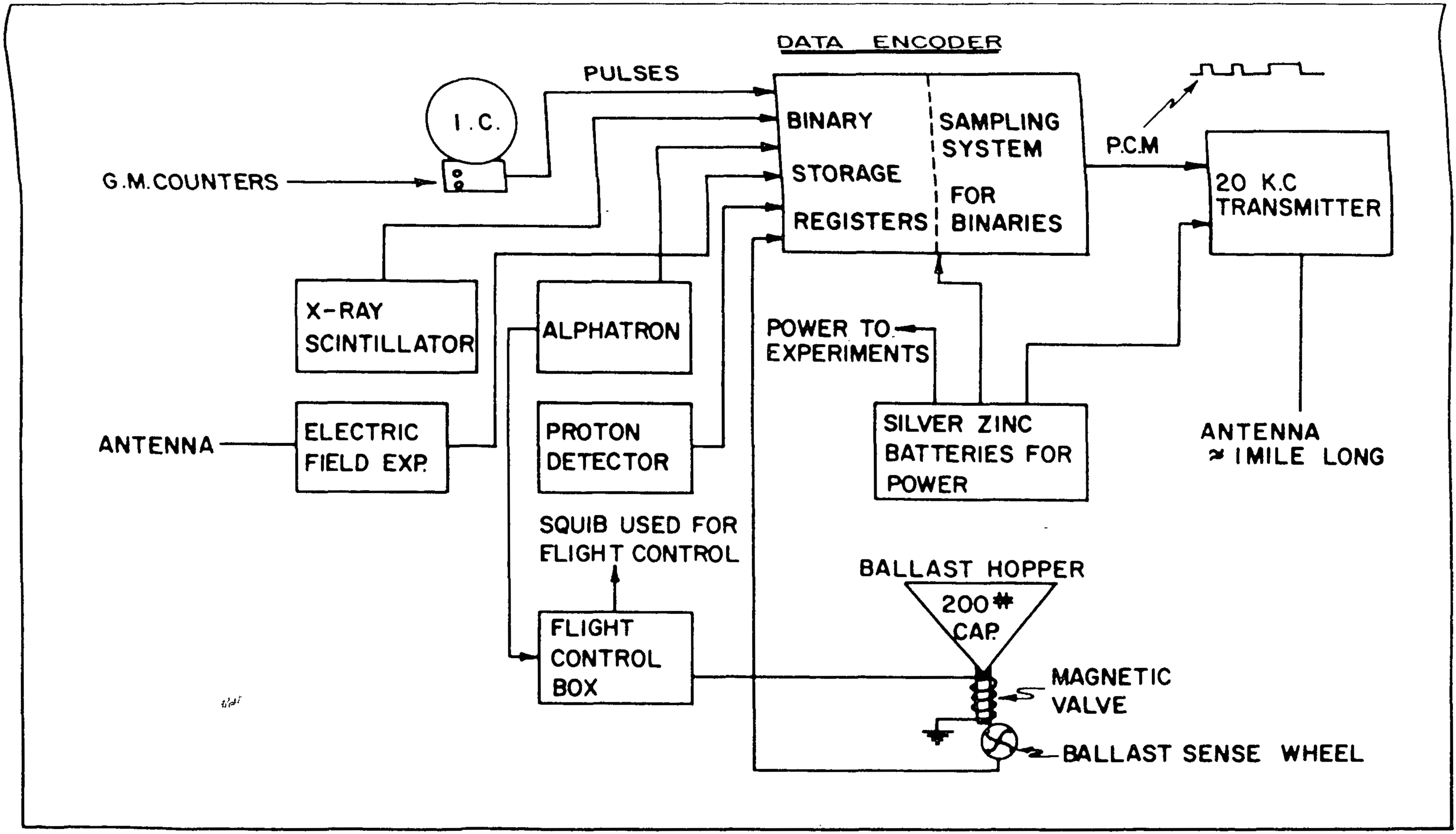
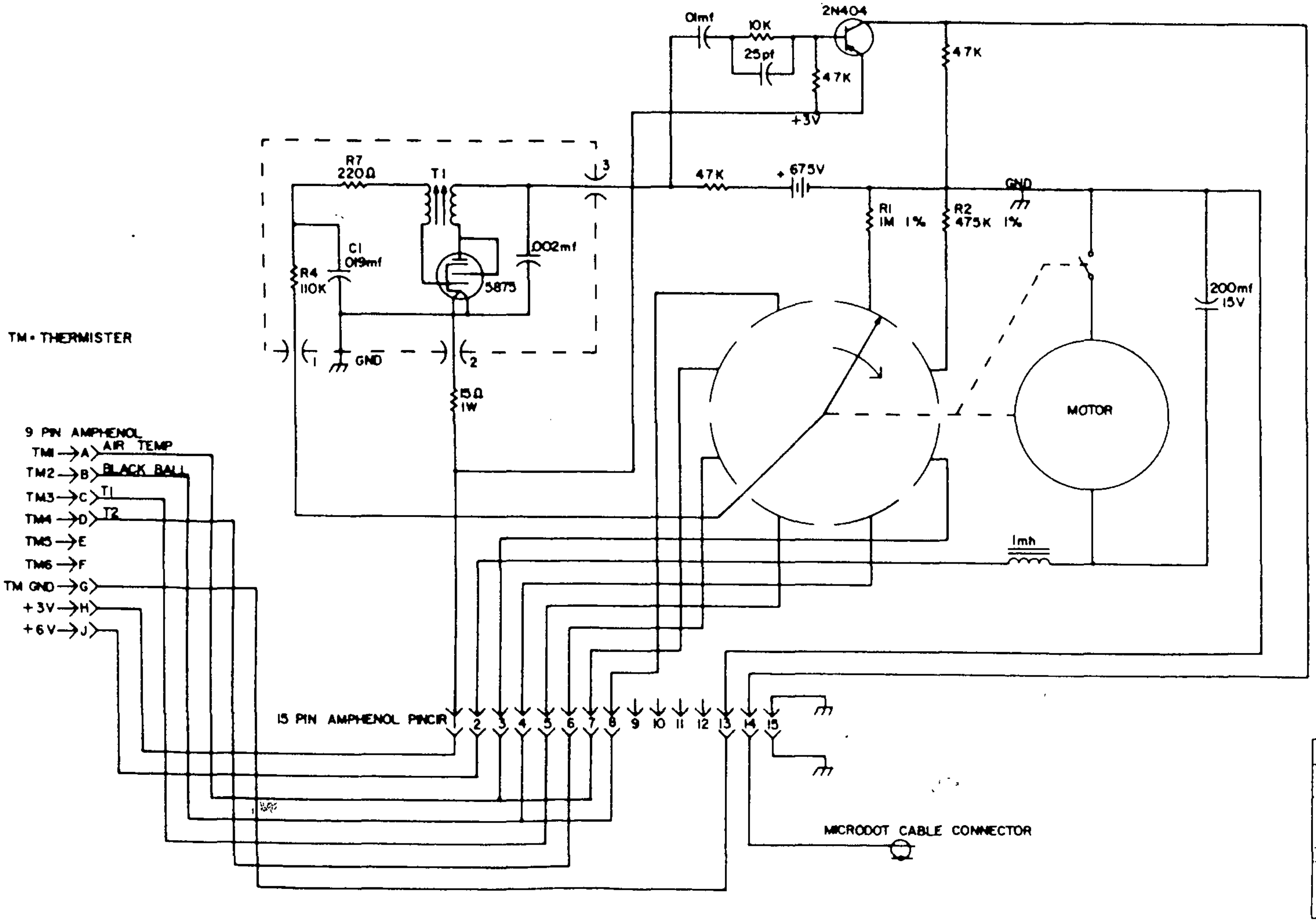

DATA ENCODER
PULSES
I.C.
G.M.COUNTERS
BINARY
STORAGE
REGISTERS
SAMPLING
SYSTEM
FOR
BINARIES
P.C.M
20 K.C
TRANSMITTER
X-RAY
SCINTILLATOR
ALPHATRON
POWER TO
EXPERIMENTS
ANTENNA
ELECTRIC
FIELD EXP.
PROTON
DETECTOR
SILVER ZINC
BATTERIES FOR
POWER
ANTENNA
≈ 1 MILE LONG
SQUIB USED FOR
FLIGHT CONTROL
BALLAST HOPPER
200# CAP.
FLIGHT
CONTROL
BOX
MAGNETIC
VALVE
BALLAST SENSE WHEEL

Figure 15

ray and atmospheric physics data. These instruments are similar to those already described in the literature or in the case of new instruments will be described in the scientific papers delineating the results of the experiments. We shall describe in this section, in detail, the α-tron pressure measuring instrument which is a new and unique development of this program, the flight control box and ballast system, the data encoder, the 70 kc transmitter and the battery power supply.

All of the information came from the various instruments and detectors into the data encoder in the form of pulses which were fed into standardized binary storage registers. The differences between the various experiments consists in the way in which the sequence of pulses was related to the primary event being measured. In the case of temperature, a blocking oscillator was used to convert the analog value of the resistence of the thermistor to a frequency of oscillation which determined the repetition rate of the pulses fed out by the blocking oscillator. A similar system was used in the ozone detector which involved phototubes and optical filters. On-off type devices such as switches were sampled directly by the data encoder. The proton detector gave a serial string of coded pulses which formed a number whose value was proportional to the ionization loss of cosmic ray particles in the proton detector. The way in which the various temperatures were sampled and encoded is shown in Figure 16 which is an electronic and cabling diagram for the Pocibo temperature box. The main element is a blocking oscillator unit taken out of the standard Weather Bureau radiosonde unit. This blocking oscillator then operates a pulse shaper whose output goes into the data encoder. The six different thermistors are scanned by a motor driven rotating switch.



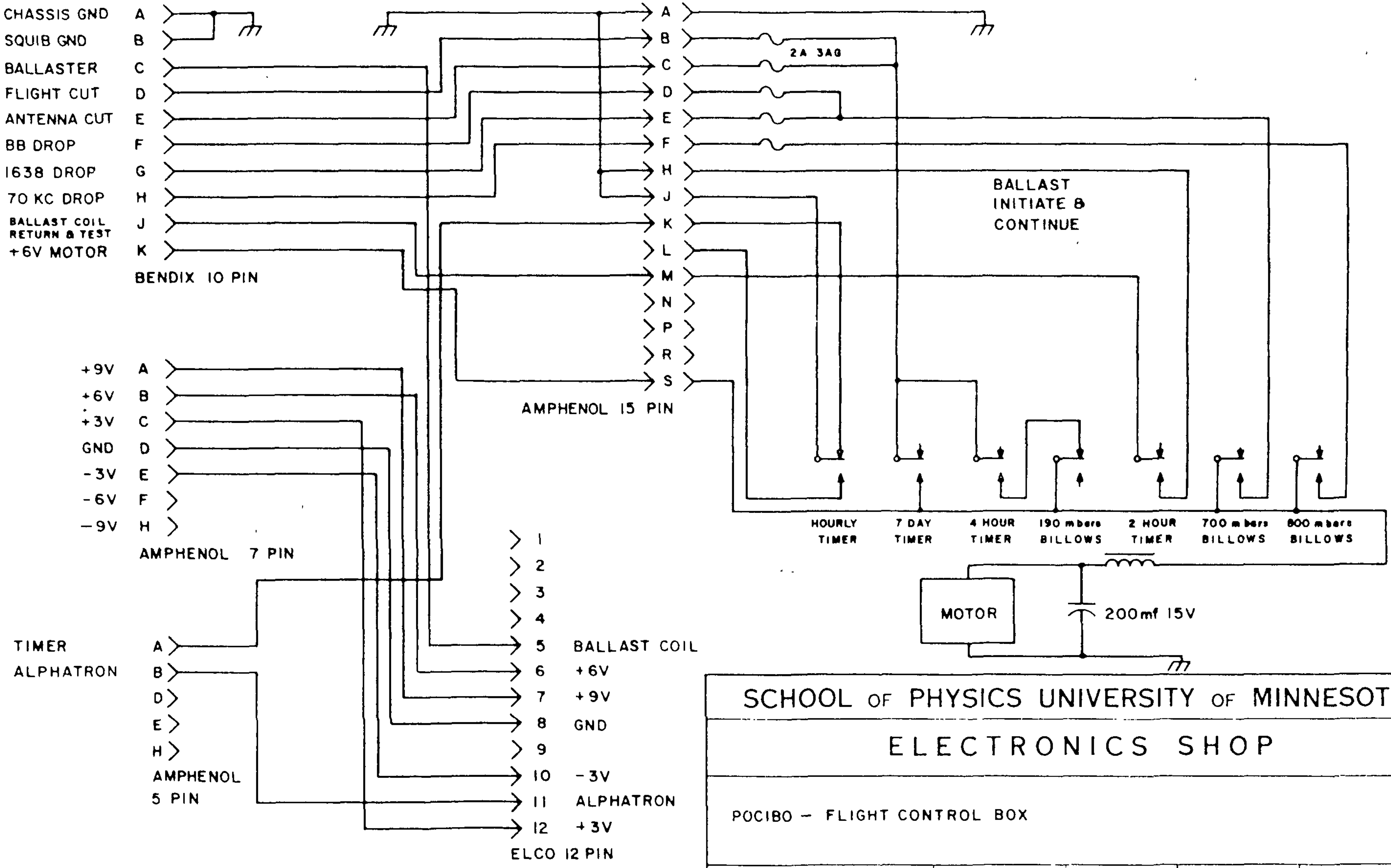
SCHOOL of PHYSICS UNIVERSITY of MINNESOTA
ELECTRONICS SHOP
POCIBO TEMP BOX

DRAWING NUMBER	DWN BY	FOR	CHECKED BY	DATE
E- -940 P	GDP	WINCKLER		1-27-64
JOB & BUDGET		CHANGE 1		
940-0641-5360		CHANGE 2		
		CHANGE 3		

Figure 18

These instruments specifically for the purpose of controlling the balloon or its droppable instruments or measuring the pressure altitude of the balloon were grouped together in one container which is called the flight control box. (See example in Figure 12). This box contains two plug-in sections one of these containing gear trains driven by a governed "Brailsford" motor which actuated the various timers for terminating the flight, initiating the ballast control and setting the safety limits for low altitude release. This board also contained various adjustable aneroid bellows equipped with micro-switches for dropping the 70 kc antenna, for releasing the black-ball radiation detector and for initiating the low altitude safety cut. Some of the switches fired squibs which released the instruments or the gondola itself from the balloon. Other switches armed the safety cut and the ballast control. A circuit is given in Figure 17.

The other card contained an α-tron pressure sensor. The α-tron also was used in conjunction with a special timing circuit to drop the steel shot ballast in a certain manner. Since the α-tron pressure gauge is a fairly unique development associated with the Pocibo program, it is described in some detail in this report. However, complete electrical circuits for the instrument are not included but are available from this laboratory. The α-tron gauge is basically a density measuring device. The density is measured by collecting the ions produced in a small chamber by an extremely low level source of polonium 210 which emits α particles and has a fairly short half-life. The ionization current is collected by a sensitive stable electrometer with a floating grid and an input capacitor. As the capacitor charges due to the collection of the ion current, a voltage ramp is produced which eventually triggers a tunnel diode discriminator and resets the instrument by shorting out the accumulated charge with a reed type relay. A block diagram for the device is shown in Figure 18. Basically, the instrument measures density.



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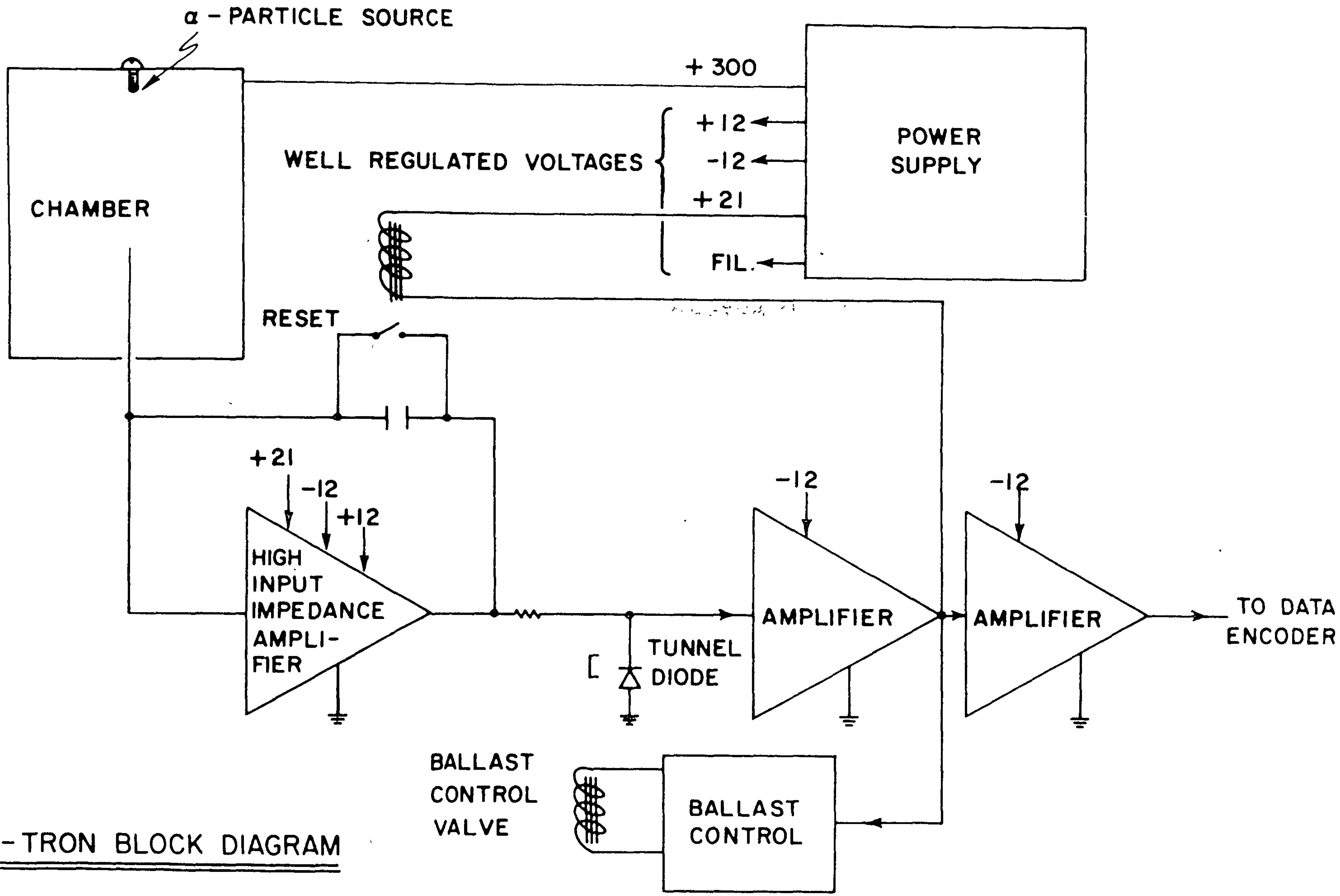
ELECTRONICS SHOP

POCIBO — FLIGHT CONTROL BOX

DRAWING NUMBER	DWN BY	FOR	CHECKED BY	DATE
E-CR-940 S	JTH	WINCKLER		2-10-64
		CHANGE 1		
JOB & BUDGET		CHANGE 2		
940-0641-5360		CHANGE 3		

Figure 17



α - TRON BLOCK DIAGRAM

Figure 10

The density is converted to the ambient pressure at which the balloon is floating by a temperature compensation. This temperature compensation is done with the proper combination of thermistors and resistors and effectively applies the gas law to the density determination to convert it to pressure. The instrument is carefully calibrated in a thermal bell jar setup so that the readings depend only on pressure and are independent of temperature over a suitable working range. A typical calibration curve showing the response of the instrument to pressure and temperature is given in Figure 19. When the α-tron is reset, a pulse is sent to the data encoder for transmission and can be sampled by the telemetry system with suitable scaling factors. The α-tron has proven to have many advantages over combinations of aneroid bellows and mechanical linkage type amplifiers. It gives what is apparently for the first time, highly reproducable pressure altitudes for balloons and also provides an almost linear response with altitude (logarithmic with pressure) into the region between 1 and 10 millibars. The α-tron that was flown on the Pocibo series had one disadvantage in that it was relatively insensitive to pressure between 1000 millibars and 600 - 700 millibars and also showed a temperature dependence in the same region. However, further development of the instrument has been accomplished which corrects these defects and, in addition, a solid state type electrometer has been substituted for the vacuum tube electrometer described herein and used on Pocibo. A further complete description of the improved instrument will be forthcoming.

The ballast system for Pocibo consisted of a conical shaped hopper which could contain from 200-300 lbs. of specially sifted and cleaned steel blasting shot. The ballast was released by a magnetic type valve with a permanent magnet which held the ballast normally in the interior of the brass orifice. When the balloon dropped below the ballast floor, a voltage would be applied to a coil which would cancel the field of the permanent magnet and release the ballast. Such systems have many advantages, but also difficulties are encountered, and it is

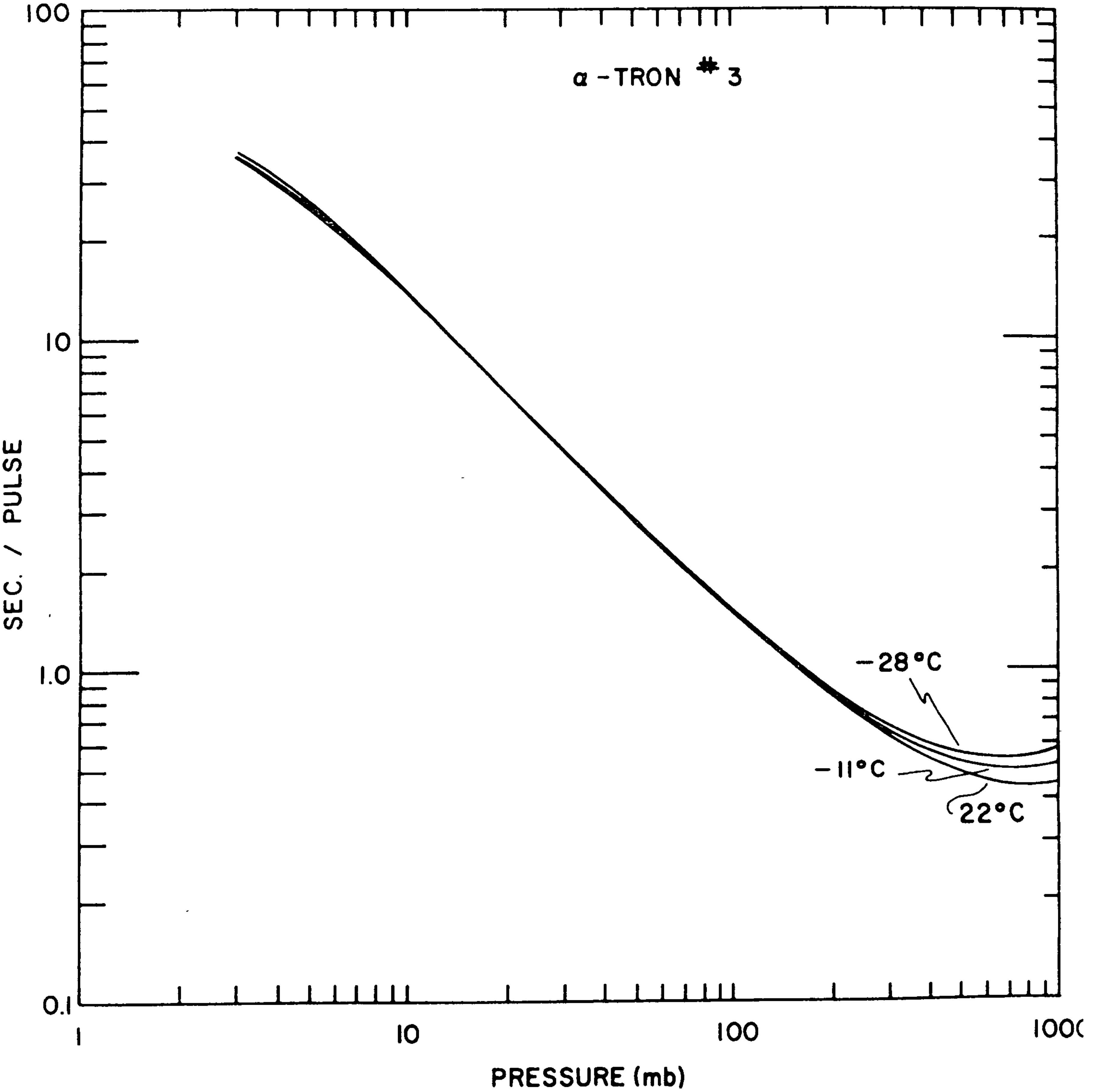
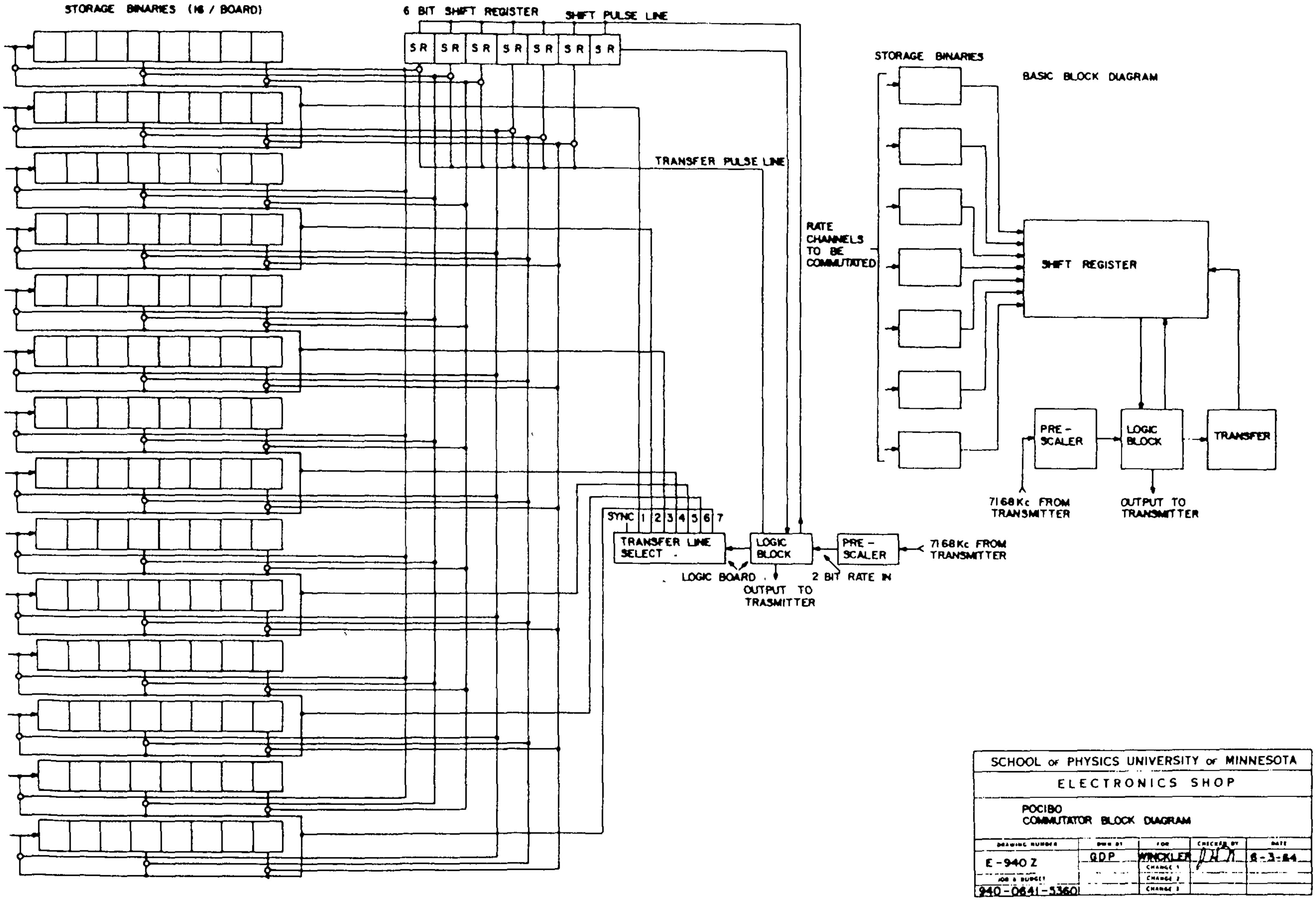

α-TRON # 3
100
10
1.0
0.1
SEC. / PULSE
1
10
100
1000
PRESSURE (mb)
-28°C
-11°C
22°C

Figure 19

very important to have an independent check that ballast is actually flowing out of the valve. This is done with a small wheel with paddles which was placed under the valve and would be caused to turn by the dropping shot. When the wheel turned, an electrical contact was made. A simple electronic circuit produced a ballast sense signal which was put on the data encoder and transmitted by the telemetry system. The system encountered some early difficulties due to the fact that the shot seemed to freeze or be retained in the hopper. This might have been due to moisture freezing in the hopper. The size of the ballast valve was increased after this to insure that ballast would be released. However, no real test of the operation of the ballast system in flight was obtained due to the bad balloon behavior. The ballast sense is obtained from the α-tron pressure gauge by a timing circuit such that a certain pulse of the α-tron starts the timing circuit and if the α-tron reset occurs before a certain fixed elapsed time, the ballast system is actuated and drops ballast to fill out the timing interval. Thus, the rate of ballast release is in a rough way proportional to the error of pressure below the ballast floor. The system is prevented from ballasting at low altitude at the beginning of a flight by a timer which enables the ballast system after several hours. Thus, the ballasting could be used to drive up a balloon which is ascending too slowly or can be used to return a balloon to ceiling if it drops from ceiling after the initial ascent.

3. Electronic Design - Telemetry.

The heart of the Pocibo telemetry system is the data encoder. A block diagram and explanation of the logic is shown in Figure 20 and all of the commutator circuits are shown in detail in Figure 21. The data encoder provides a means for sampling the information on a set of storage binaries in time sequence, arranging the samples in a serial string of bits for modulating the telemetry transmitter. In a system of this type which commutates the various instruments, it is necessary to reconcile the commutation rate which, in turn,


STORAGE BINARIES (16 / BOARD)
6 BIT SHIFT REGISTER
SHIFT PULSE LINE
S R
TRANSFER PULSE LINE
RATE CHANNELS TO BE COMMUTATED
STORAGE BINARIES
BASIC BLOCK DIAGRAM
SHIFT REGISTER
PRE-SCALER
LOGIC BLOCK
TRANSFER
7168Kc FROM TRANSMITTER
OUTPUT TO TRANSMITTER
SYNC 1 2 3 4 5 6 7
TRANSFER LINE SELECT
LOGIC BLOCK
PRE-SCALER
7168Kc FROM TRANSMITTER
LOGIC BOARD
OUTPUT TO TRASMITTER
2 BIT RATE IN
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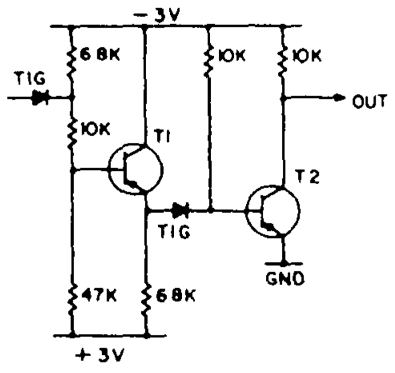
ELECTRONICS SHOP
POCIBO
COMMUTATOR BLOCK DIAGRAM
DRAWING NUMBER
E-940 Z
JOB & BUDGET
940-0641-5360
DWN BY
GDP
FOR
WINCKLER
CHANGE 1
CHANGE 2
CHANGE 3
CHECKED BY
DATE
8-3-64

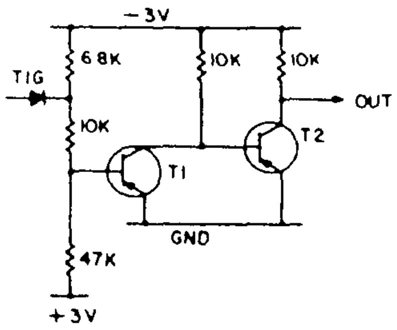
Figure 20

POWER INVERTER



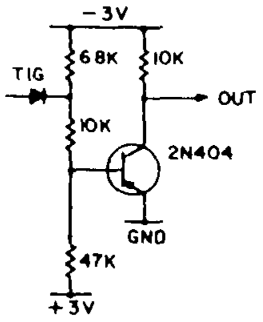
β MIN	
T1	18
T2	22

DOUBLE INVERTER



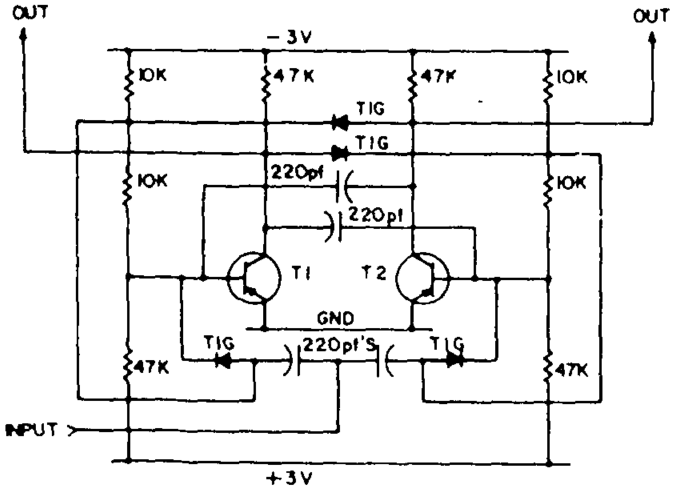
β MIN	
T1	10
T2	6

SINGLE INVERTER



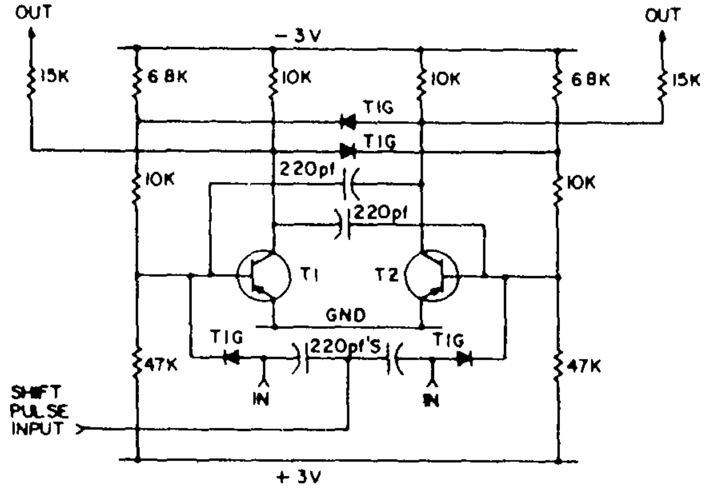
LOAD	β COLD
1	15
2	22
3	28
4	35

BINARY



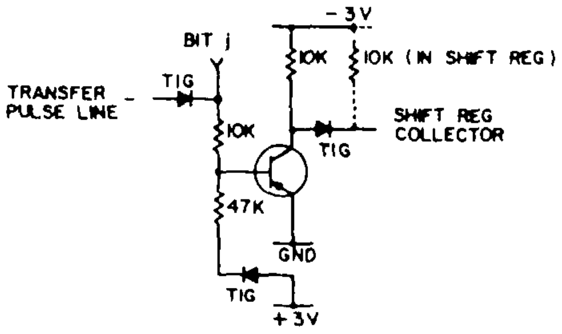
LOAD	β MIN
0	15
1	22
2	28
3	35
4	41
5	48

SHIFT REGISTER



β MIN	
T1	15
T2	15

SINGLE INVERTER FOR SHIFT REGISTER TRANSFER



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ELECTRONICS SHOP

POCIBO
COMMUTATOR CIRCUITS

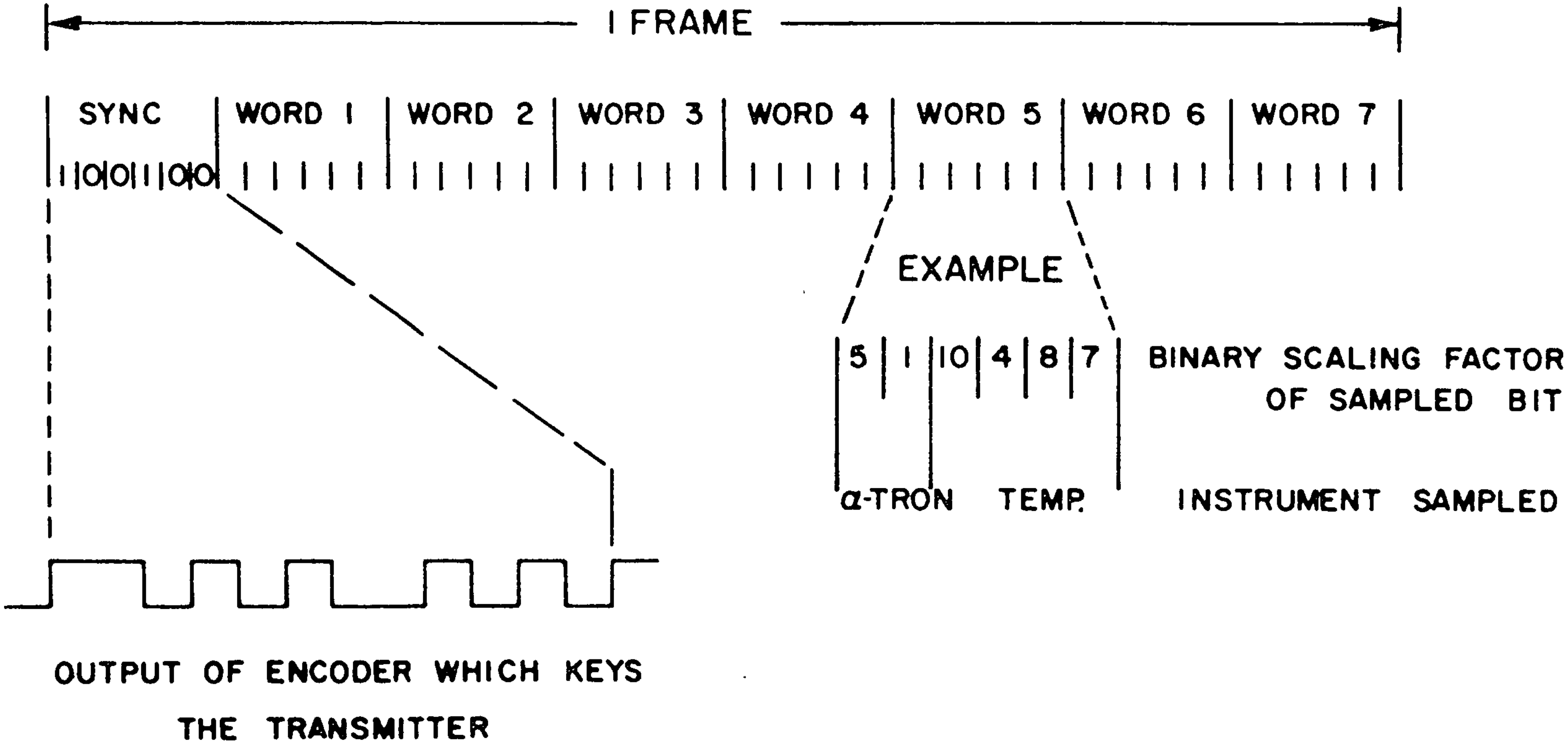
DRAWING NUMBER	DWN BY	FOR	CHECKED BY	DATE
E-940Z	GDP	WINCKLER		6-10-64
JOB & BUDGET		CHANGE 1		
940-0641-5360		CHANGE 2		
		CHANGE 3		

is determined by the available bandwidth of the telemetry system with the dynamic range and desired statistical accuracy of the various experiments. Some of the experiments were of the simple counting type in which the transitions of a binary were recorded as a function of time. Some of the experiments had pulse height analyzers to give proportional information about cosmic ray particles. These experiments, such as the proton detector, had 64 pulse height levels per channel to be read out. Other experiments, such as housekeeping information, had only the requirement to determine if a switch was on or off and with a time accuracy much less than the cosmic ray experiments. It was decided to make available a dynamic range of 1000 to 1 for the counting experiments. The counting rate accuracy of the counting experiments was determined by the length of time over which the rate was averaged. It was decided to aim at a statistical accuracy of around 2.5%. This means that since the error in time introduced by the commutator into the rate determination is determined by the sampling time for a particular bit, about 40 samples should be taken for each expected transition of the bit in question. To reconcile this with the dynamic range, 8 storage binaries arranged as a scaler were sampled at the 0, 4, and 8 binary level in the data encoder. Sufficient pre-scaling was used on the counting experiments so that with the lowest expected count rate the 0 binary would be sampled about 40 times per transition (i.e. would change state about once/minute). If the rate increased, the accuracy could be preserved by using the 4 or 8 binary sample. The time resolution could be increased by using the 0 binary, but with loss of accuracy. In the case of the pulse analyzing experiments, the storage binaries were used to accumulate a number proportional to the pulse height measured. These numbers were counted into the storage binaries very rapidly when the event took place and would remain until read-out by the telemetry system. The information from each experiment on the storage binaries or on single binaries is commutated by a transistorized commutator into a serial string of bits. This string of bits, for convenience, is broken down into a series of six bit blocks or data words. One of these words in each frame is used for synchronizing the data frame and is always the same. It was the practice to encode the flight number as the synchronizing word so that if the signal was heard at any time, it would be possible to tell immediately which Pocibo flight was being recorded. This identification was also useful for data analysis where there were many tapes to analyze. The sequential string of bits then modulated the telemetry transmitter. The bit format for Pocibo IV is shown as an example in Figure 22. The ten watt, 71.68 kc transmitter was keyed on and off by a method called differentially coherent phase reversal keying. This method is, in effect, like using a sub-carrier equal to the bit rate. Although in principle, it would be possible to record the bit rate at the receiving station as if it were a sub-carrier of frequency equal to the bit rate, in practice, the data was recorded in the form of a 935 cycle per second carrier keyed as described above. This carrier was produced by the secon local oscillator in the 70 kc super heterodyne receiver and was recorded at 1-7/8" per second tape speed.

The counting experiments fed the data encoder a standard pulse (positive 3 volt, 5 microsecond with a rise time of 1 microsecond or less) which was counted by the storage binaries. On the other hand, the pulse analyzing experiments fed their pulses rapidly, immediately after each event into a string of six binaries, each of which was sampled and constituted a single word in the telemetry system. This form of storage register, used only for pulse height analysis, also had a remote re-set command.

The data encoder transferred blocks of six bits into a shift register whic shifted the bits into the transmitter and then accepted a new set of six bits (See Figure 20). Before the bits entered the transmitter, they underwent a chang

BIT FORMAT FOR POCIBO IV



[illegible]

in that each logic zero level from the shift register triggered a binary. Each shift pulse also triggered the binary. The output of this system thus keys the transmitter on and off with a phase reversal keying in which the phase of the effective sub-carrier (frequency equal to the bit rate) is changed one-half cycle. An example of the transmitted signal obtained from a set of bits is included in Figure 22.

The exact frequencies used for Pocibo (71.68 kc and 70.656 kc) were chosen because the VLF band is fairly free of known stations there and that these frequencies are multiples of 16 cycles per second which is the basic bit rate. The crystal controlled transmitter was within ± .005% of the previously mentioned frequencies. This made it possible to use the bit rate as an accurate and stable relative time base for the computer. The absolute time had to be indexed into the system, and this was done from known signals on the telemetry channel. In the early flights at Barrow, several other back-up radio frequencies were used, 1638 kc and 95 megacycles beside the 70 kc. These other frequencies were abandoned by the time of the Norway operation because of the complications of deploying the antennas and producing the proper radiation pattern around the Pocibo package.

The six basic circuits of the electronic commutator are shown in Figure 21 and were mounted on printed circuit boards. The boards supplied the necessary flexibility for commutating any number of experiments in any desired format. They were all mounted in the data encoder box (See also Figure 12). The circuits were designed to work reliably from -30° C to +30° C with a supply voltage that changed 30%. The binaries used 4 milliwatts per circuit, the and gates 2 milliwatts per circuit and other circuits, 4 milliwatts per circuit.

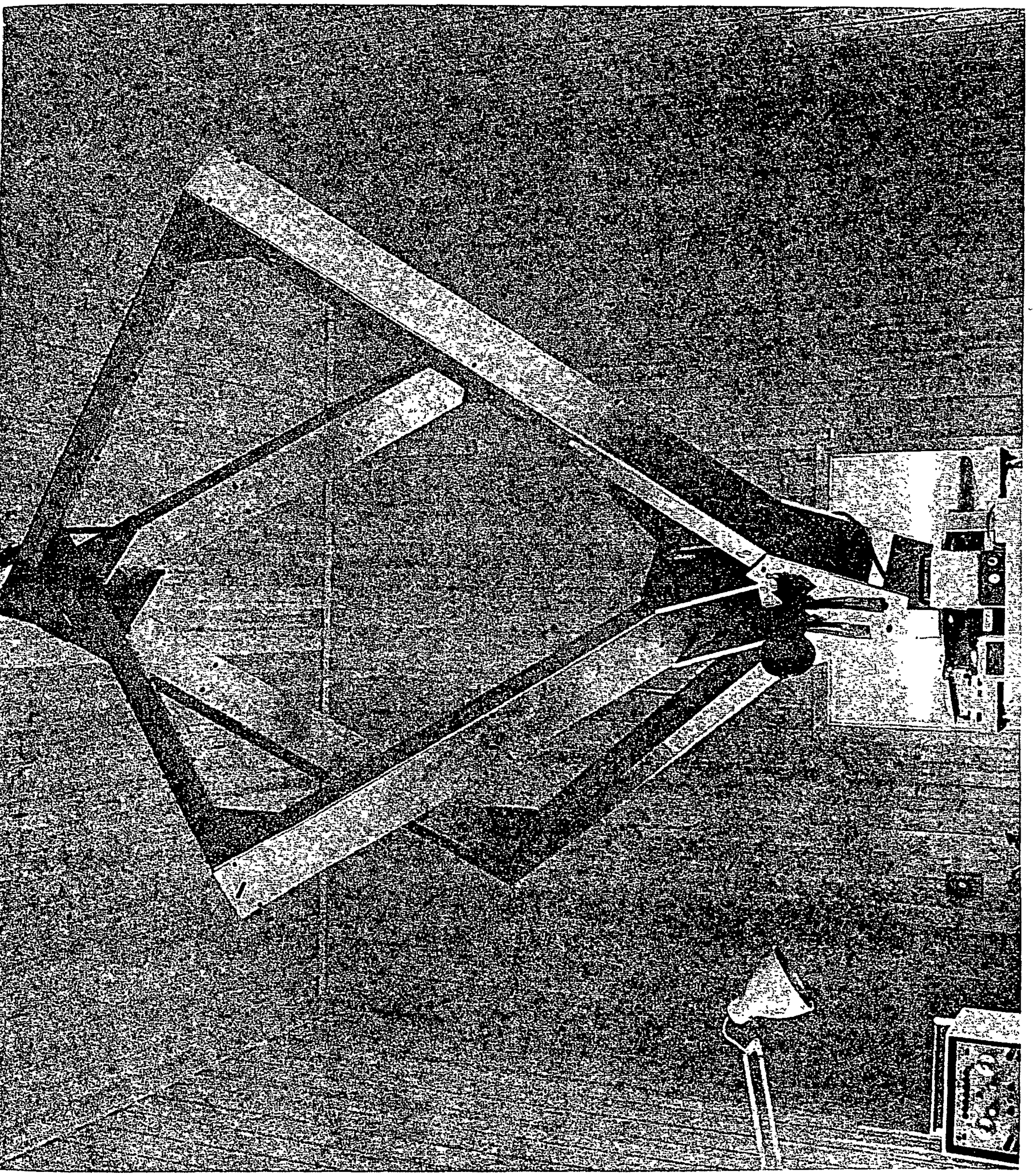
4. Battery Power Supply

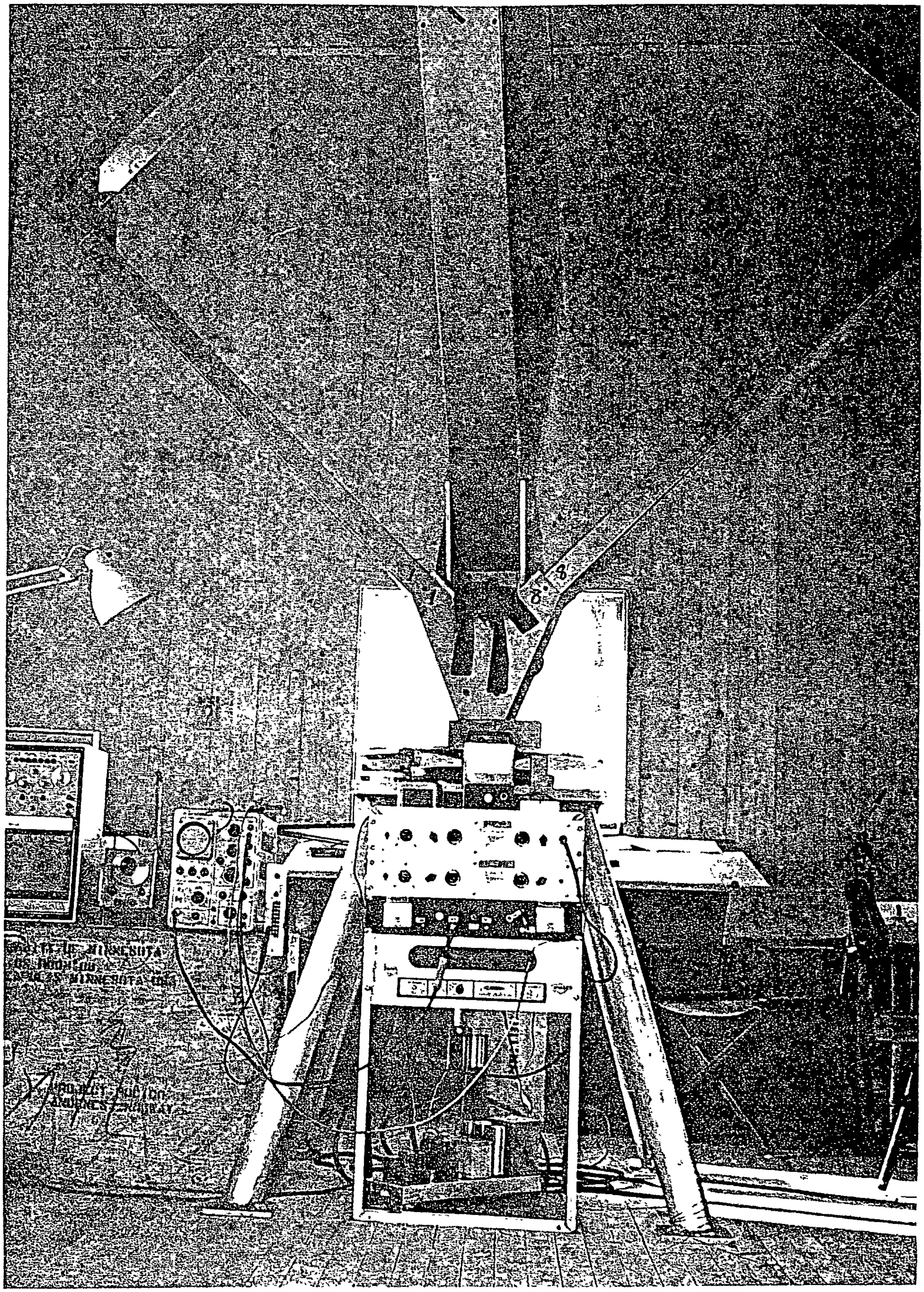
The airborne system was supplied with power from silver zinc batteries. We used Gould National cells. These batteries have a large ratio of watt-hours per pound (70) compared with zinc manganese cells (25), nickel-cadmium cells (14) and lead acid cells (15). The mercury battery (50 wh/lb.) and alkalie battery (40 wh/lb.) come closest to the silver zinc battery except that all of the previously mentioned batteries lose capacity as the temperature decreases. As an example, lead acid batteries have a capacity of 2 wh/lb. at -40°C while silver zinc cells are down to about 30 wh/lb. at -40°C. Silver zinc cells cost about one dollar per watt-hour, which is about three times the cost of the next most expensive battery (mercury). The entire gondola with experiments used about 12 watts of power, six watts were used for the 71.68 kc transmitter. This entire battery pack weighed 40 lbs. and supplied power for 168 hours. The battery pack supplied experimenters with six unregulated voltages (± 3, ± 6 and ± 9 volts). The silver zinc cells have a very flat (± 3%) discharge characteristic after the initial discharge from 2 volts per cell to 1.5 volts cell (about 10% of the life of the battery is used up before the 1.5 volt plateau is reached). The internal impedance of the batteries is also very low ($<.01\ \Omega$ for a 40 amp hour cell) but increases with decreasing temperature.

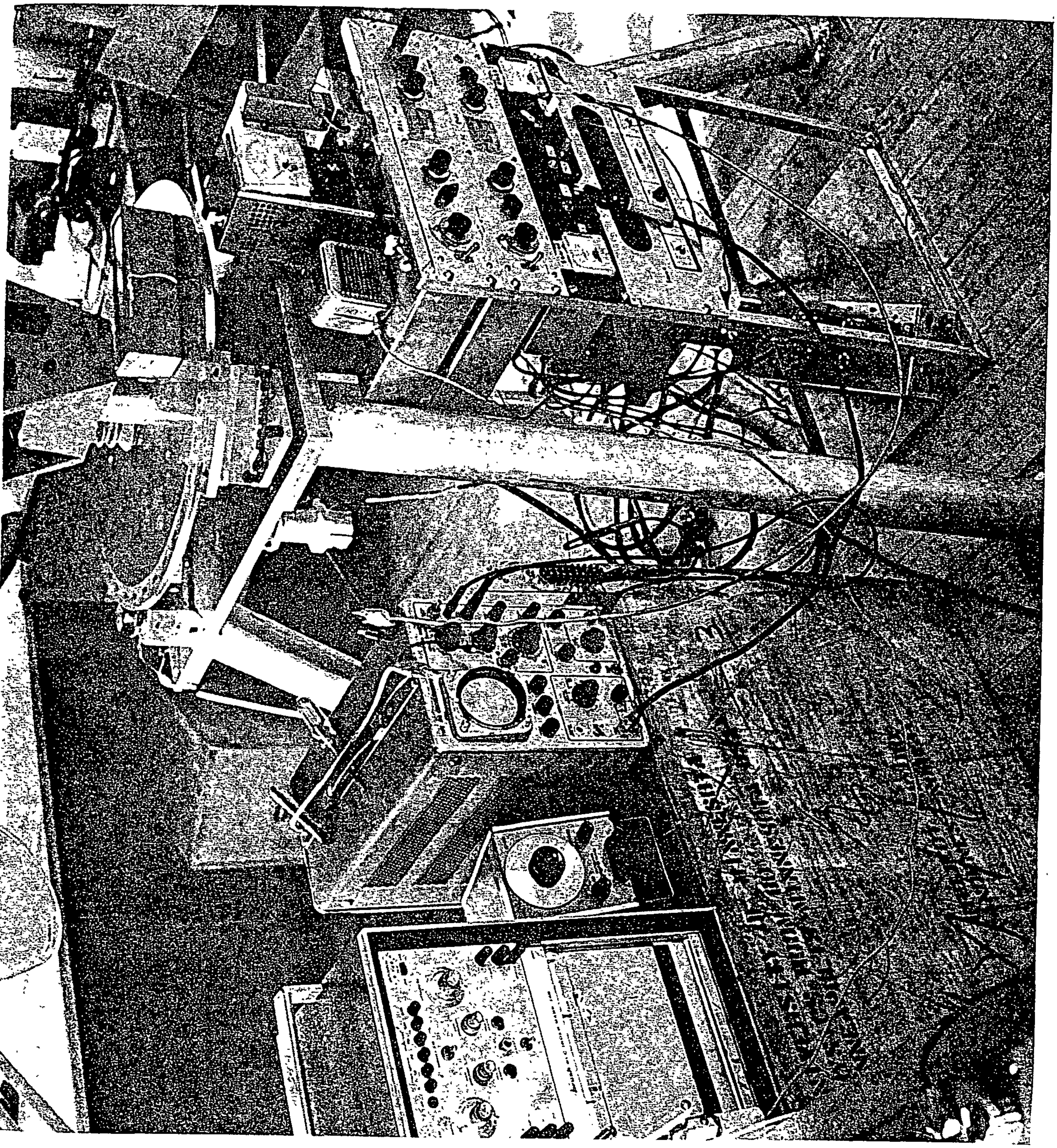
D. Ground Station and Direction Finding.

The requirements for the ground station include both the recovery of telemetered scientific data from the balloons and trajectory determination by triangulation using direction finding equipment. Telemetry reception requires only that the station be within radio range of the balloon, but at least two stations and a suitable base-line distance are required for triangulation. Accordingly, ground stations were placed at Barrow, Alaska and on the drifting station T-3 for the initial Alaskan flights in January and February 1964. These two stations provided a minimum capability for locating the balloon at locations not too remote from the launch site at Barrow. In the Norway operation in the summer of 1964, tracking stations were located at Andenes, Norway near the launch site, at Thule, Greenland and at Barrow, Alaska. The ground station equipment was housed both at Barrow and Andenes in special weather proof buildings constructed locally for thatpurpose. The T-3 installation was housed in an abandoned radome located near the station camp. The Thule station was housed in one of the field units of the Army Arctic Test Center group.

The receiving equipment in the ground stations consisted of loop antennas which were designed and built at the University of Minnesota. The loops were designed to have a thermal noise small compared with the lowest expected radio frequency noise level. This was actually achieved as the lowest RF noise level encountered was 0.1 μv/meter in the receiver bandwidth of 100 cycles at 70 kc measured on February 25, 1964, at Barrow. This noise level was 7 db above the thermal noise of the loop antenna. The loop system in the early spring operation of 1964 at Barrow consisted of a single electrostatically shielded loop about six feet on a side composed of 20 turns of 3/16 in. diameter copper bus. A photograph of the loop is shown in Figure 23. Actually, the loop shown in Figure 23 includes also an inner loop which was added to the system for the summer operation and will be described more fully below. The loops were demountable as the copper bus was in the form of straight sections which were soldered together at the corners and the loops could be completely disassembled for crating. An accurate azimuth circle with vernier was attached to the loop base as shown in the second and third views, Figures 24 and 25. Radio bearings were first determined for the Barrow launch operation by nulling the balloon signal and measuring the angle on the azimuth circle. As the operation proceeded, several more accurate techniques were used with the single loop. For example, bearings of equal signal strength on each side of the null were averaged. This was done by hand and the readings recorded in the notebook. An alternative method consisting of swinging the loops slowly through the null and recording the loop position by a potentiometer pick-off and the RF signal strength simultaneously on a two channel chart recorder. It was necessary, of course, to




7
8
MINNESOTA
MINNESOTA



determine the bearing of true north for a reference which was done by sun sightings and local surveying. A small test loop which could be accurately aligned for this reference and was placed some distance from the radio receiving building with a signal generator operating at 70 kc.

The radio receivers were designed and built for the Pocibo project by Dr. George Swenson of the University of Illinois and had a noise figure of +1 db. The receivers were crystal controlled for stability and ease of tuning. In Figure 25 may be seen a rack in which the top two units are two of the receivers delivered by Dr. Swenson. The telemetry signals were tape recorded on a Tanberg tape recorder driven at 1-7/8th inches per second by a precision frequency source to maintain good stability. This stability is needed because of the digital data reduction system. A 100 watt Bogen power amplifier driven by a crystal controlled 60 cycle oscillator source supplied power to the tape recorder and to clocks in the station. Power to the entire radio receiving station was supplied by a diesel driven alternator. For example, an Onan 3 kilowatt installation was used at Norway and was very satisfactory. The generator was located about 150 ft. from the station and contributed no noise provided that the power cables to the station were carefully shielded and grounded.

Radio bearings with the single loop system used in the early flights were taken from Barrow and T-3 during the flight of Pocibo IV. These results are plotted in Figure 26. This figure shows the bearings as measured from T-3 and from Barrow. The balloon moved almost directly eastward from Barrow as can be seen and, therefore, the T-3 bearings decreased with time. A number of interesting features show on this figure, for example, shortly after the antenna drop when the signal was first heard at T-3 the bearings deviate quite a bit from the expected value shown by the line marked Barrow from T-3. This is probably associated with the fact that the balloon was heard at T-3 on skywave because of its low altitude and also possibly because

(Nc p 59)

the very long antenna was going through sheer layers in the atmosphere and was not hanging vertically. Similarly, towards the end of the flight there is some scatter of the points as observed both at Barrow and T-3 which may reflect the skywave propagation becoming more important and also the antenna curling around as the unit descended on the parachute. It is clear that if the signal is being received on skywave and is reaching the station propagating downward from the D layer, that although the wave may be plane polarized, the polarization vector may be rotated if the antenna is not vertical, therefore producing an erroneous bearing. Figure 26, resulting from the Pocibo IV flight, is the only example where the 70 kc system was used on the balloon for direction finding because of balloon failures. The angular accuracy appears to be of the order of one degree if one uses smoothed curves drawn through the points as the balloon drifts and changes its bearing. The planned technique was to take at any given instant of time the directions given by the curves from the various tracking stations and compute the position by triangulation.

A major difficulty with the single loop system is that it is not suitable for nulling on the signal and at the same time receiving the telemetry data. Accordingly, in the interval between the Barrow operation and the Norway operation a few months later, another loop system was designed and constructed with a null loop and a sense loop arranged at right angles on the same mounting. This is actually the system shown in Figures 23, 24 and 25 and was installed and used during the Norway operation and also at the Thule monitoring station during that time. At the same time, an automatic servo system was developed to aim the loops at the balloon. The servo system was capable of obtaining more accurate direction values in the presence of noise than could be obtained manually. The servo system was basically a cross correlation device (see Figure 27). The signal from one of the loops received through one of the receivers was multiplied by the signal from the other loop and the second receiver. The multiplication of the two signals was

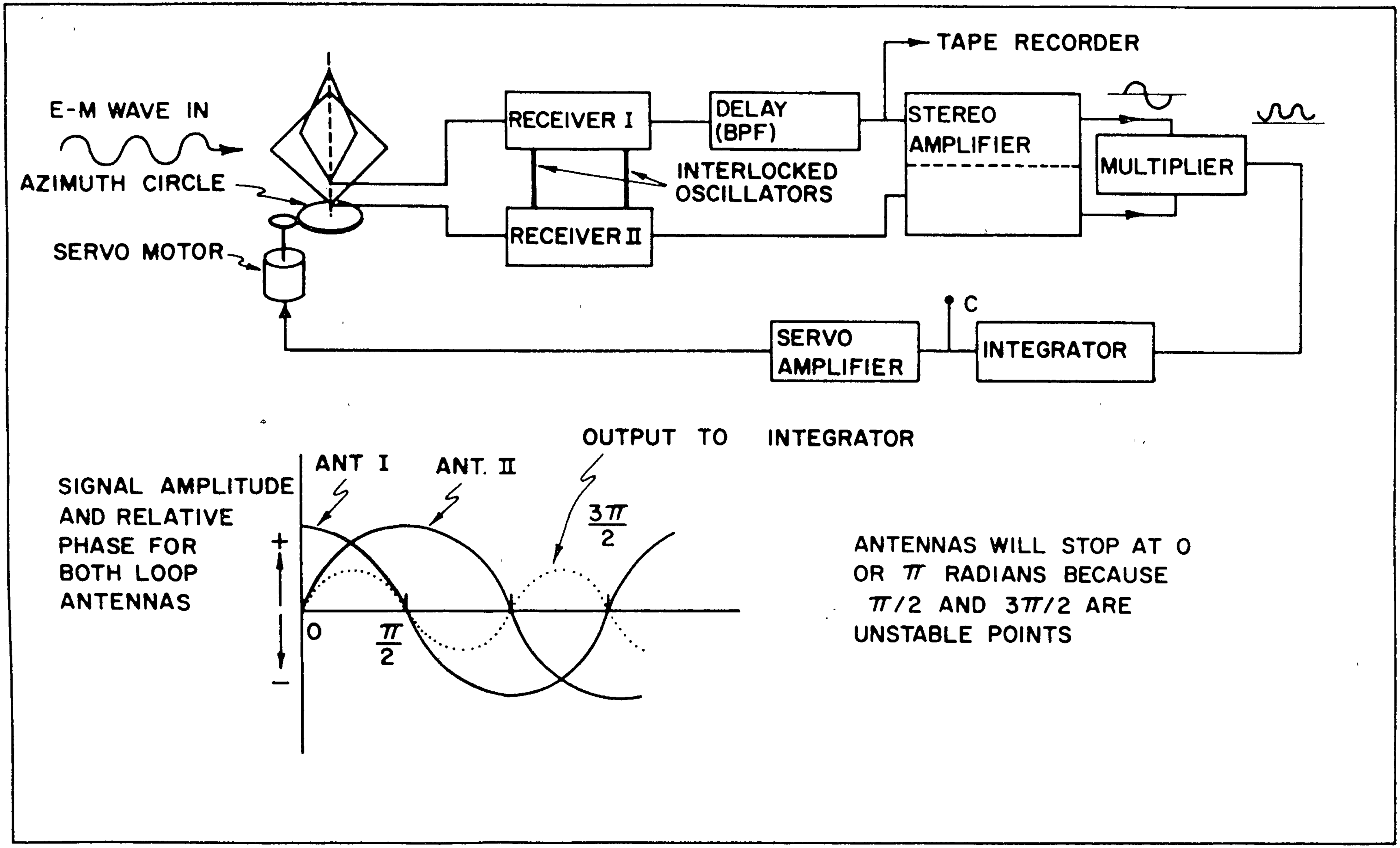

E-M WAVE IN
AZIMUTH CIRCLE
SERVO MOTOR
RECEIVER I
RECEIVER II
INTERLOCKED OSCILLATORS
DELAY (BPF)
TAPE RECORDER
STEREO AMPLIFIER
MULTIPLIER
C
SERVO AMPLIFIER
INTEGRATOR
OUTPUT TO INTEGRATOR
ANT I
ANT. II
SIGNAL AMPLITUDE AND RELATIVE PHASE FOR BOTH LOOP ANTENNAS
+
−
0
π/2
3π/2
ANTENNAS WILL STOP AT 0 OR π RADIANS BECAUSE π/2 AND 3π/2 ARE UNSTABLE POINTS

Figure 27

accomplished by a magneto-restrictive resistor bridge (American Aerospace Controls, Inc. Model No. MMA 3002 Mistor Multiplier). The two inputs of this multiplier were driven by the 935 cps signals from the two super-heterodyne receivers which were amplified by a dual channel power amplifier. To maintain the two receiver phases constant for this purpose, the local oscillators in one receiver were used for both receivers.

The output of this multiplying device was integrated with a time constant of 21 seconds which provided an enormous discrimination against noise. Any difference in voltage from zero from the integrator drove the servo motor in such a direction as to reduce the difference. This system, like the simple system described earlier was calibrated for direction very accurately using a small 70 kc radio frequency signal generator located in a precisely known direction from the radio building.

If the received signal is a vertically polarized ground wave, the plane of the sense antenna will come to rest in the direction of the incoming wave. If the plane is not vertically polarized, and the incidence is not horizontal, the plane of the sense antenna will come to rest in the direction of the horizontal projection of the magnetic vector of the wave. The functional relationship for error in direction is:

$\tan E = \tan P \sin A$ where E is the error in bearing, P is the rotation from vertical polarization and A is the angle of incidence. (See Figure 28). If the incident wave is elliptically polarized, the plane of the sense antenna will come to rest in the direction of the horizontal projection of the major or minor axis of the ellipse if the phase change in both channels from antennas to multiplier is the same. However, if there is a relative phase difference introduced between the two channels, the antenna will point in a direction away from the horizontal projection of the major or minor axis with the same functional relationship given above where E is twice the error. Tan P is minor axis over major

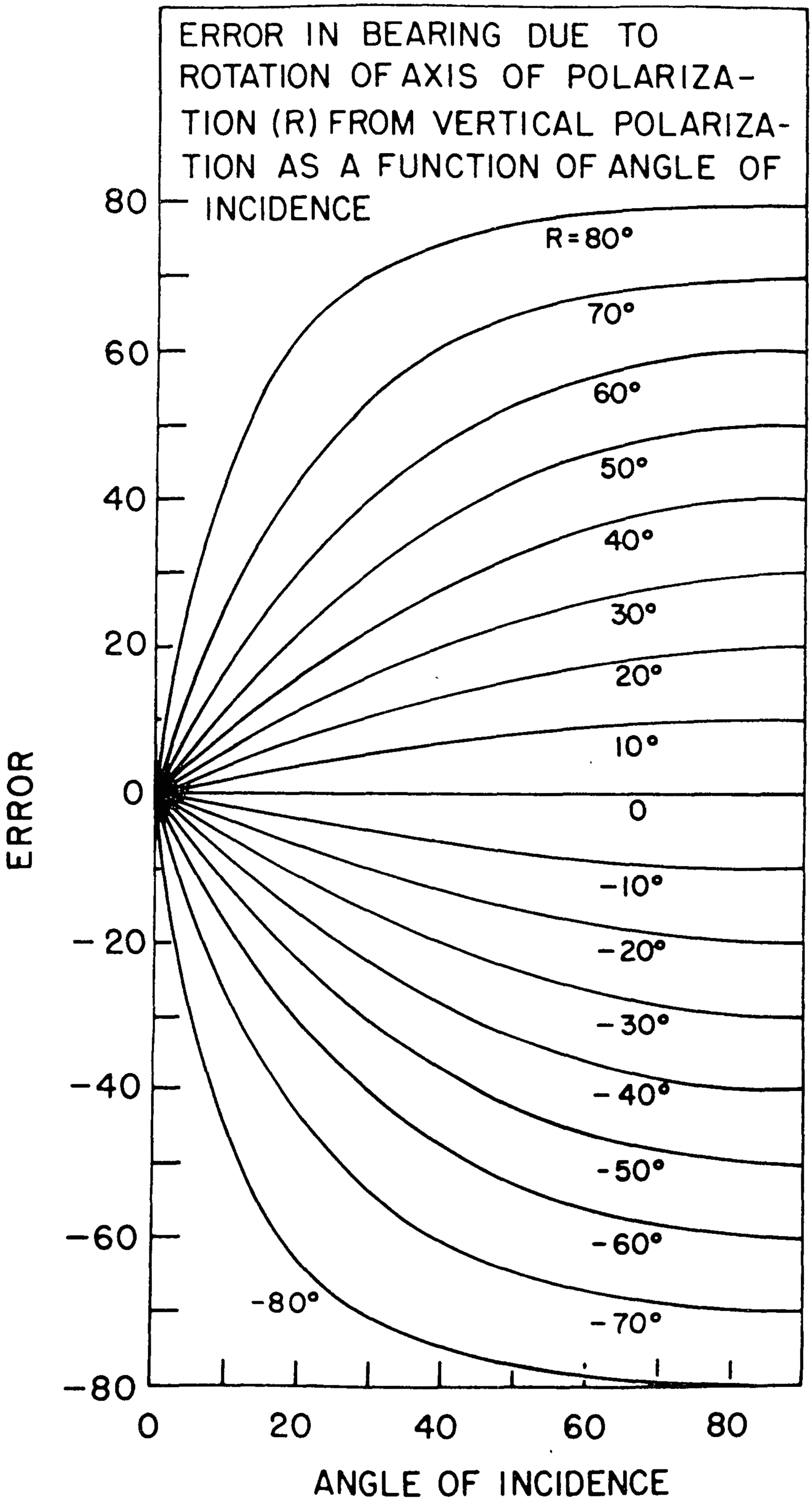

ERROR IN BEARING DUE TO ROTATION OF AXIS OF POLARIZATION (R) FROM VERTICAL POLARIZATION AS A FUNCTION OF ANGLE OF INCIDENCE
R=80°
70°
60°
50°
40°
30°
20°
10°
0
-10°
-20°
-30°
-40°
-50°
-60°
-70°
-80°
80
60
40
20
0
-20
-40
-60
-80
ERROR
0
20
40
60
80
ANGLE OF INCIDENCE

Figure 28

axis of horizontal projection and A is twice the phase difference (Figure 29).

From both the Barrow and Andenes monitoring sites, accurate bearings were taken on certain fixed stations to check the operation of the direction finding equipment. During the Barrow operation bearings were taken by the single loop hand method on the Thule and Halifax radio teletype stations operating on 77.15 kc and 73.6 kc respectively. The results of these measurements are shown in Figure 30 as a map using the gnomic projection with an estimate of the error in bearing obtained from the scatter of points taken at various times. Both of these transmitters are very high powered teletype stations using the frequency shift keying method. Measurements of the signal strengths of these stations were mentioned earlier (sec. III, "B", 2) and the Thule station seems to have been received on groundwave but the Halifax station produced a signal strength corresponding to an intermediate value between ground and skywave which is related to its greater distance from Barrow.

During the summer operation at Andenes, sightings were made on a series of Decca type navigational stations which are mainly grouped around the North Sea-British Isles region but also with a group serving the Gulf of St. Lawrence area. These stations were useful for checking out the direction finding as they operate on a continuous tone and have modest power. A reasonably good bearing was obtained for the group at Newfoundland, 2700 miles distance from Andenes, but the North Sea group all gave large bearing errors, consistently in the same direction and which come from, at present, unknown causes. Possible explanations are coastline effects due to the mountains or seacoast near the Andenes tracking station or systematic effects produced by the phase differences of the four stations in each group as seen at the receiving site. This might result in a difference between the wave normal and the wave vector for the incoming radio frequency signal. The possibility of interference between ground and skywave and some polarization effects may also be present. All of the Andenes bearings were taken with the automatic servo

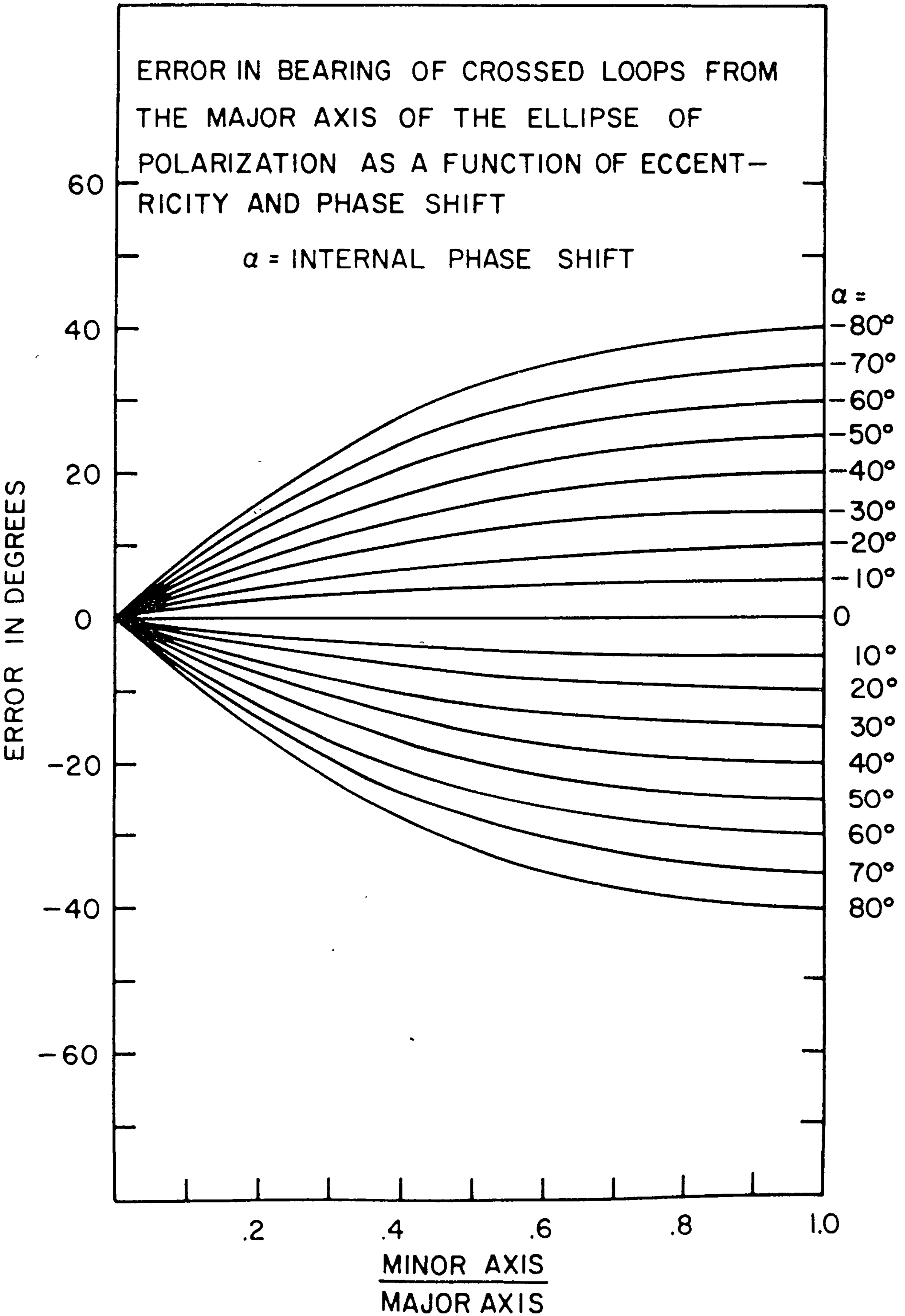

ERROR IN BEARING OF CROSSED LOOPS FROM THE MAJOR AXIS OF THE ELLIPSE OF POLARIZATION AS A FUNCTION OF ECCENTRICITY AND PHASE SHIFT
α = INTERNAL PHASE SHIFT
ERROR IN DEGREES
60
40
20
0
−20
−40
−60
.2
.4
.6
.8
1.0
MINOR AXIS / MAJOR AXIS
α =
−80°
−70°
−60°
−50°
−40°
−30°
−20°
−10°
0
10°
20°
30°
40°
50°
60°
70°
80°

Figure 23

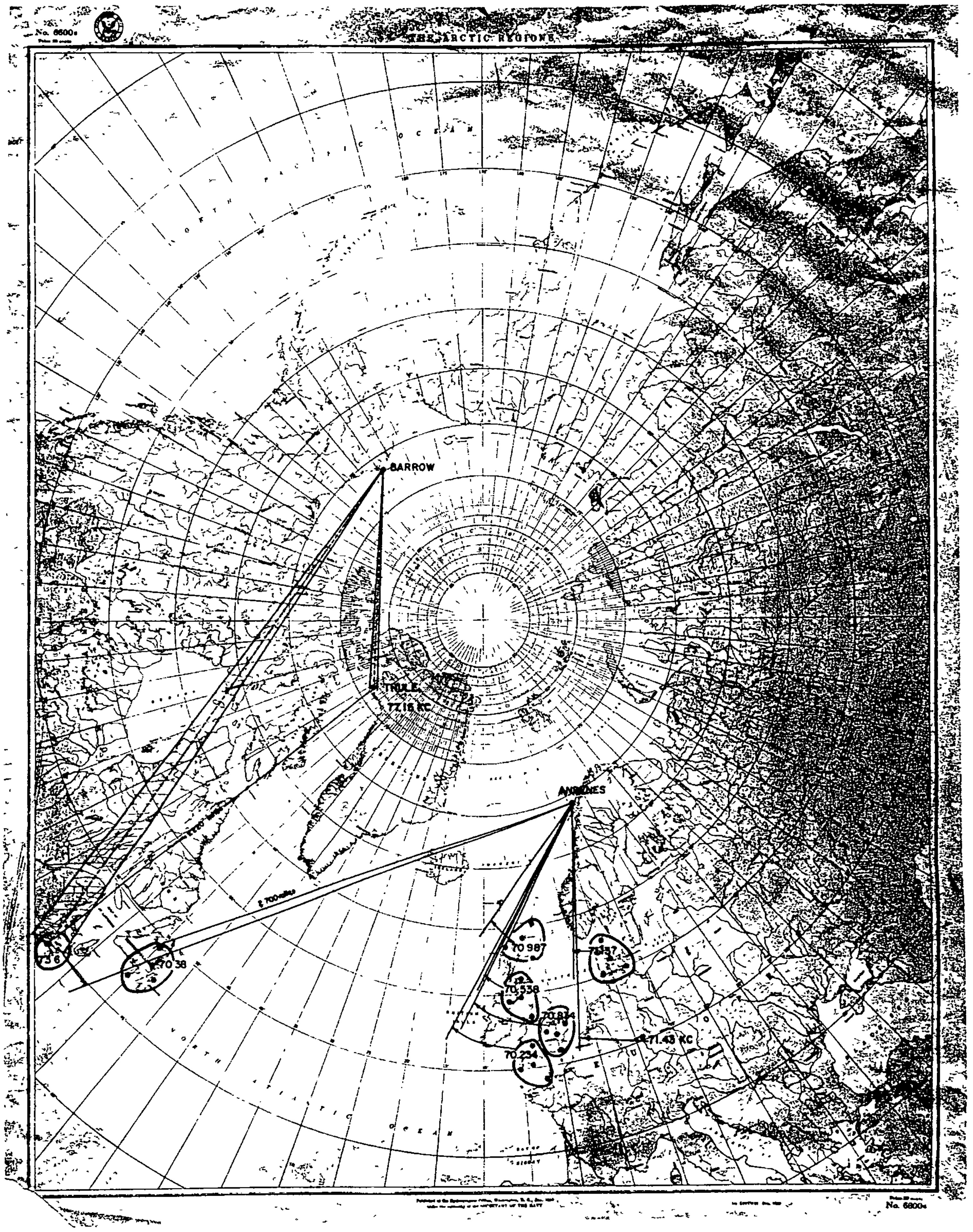

No. 6600
THE ARCTIC REGIONS
NORTH PACIFIC OCEAN
BARROW
THULE
72.16 KC
ANDENES
2,700 miles
73.6
70.38
70.987
70.538
70.814
70.234
71.43 KC
NORTH ATLANTIC OCEAN
No. 6600

Figure 30

system described earlier. It seems that these large bearing errors may be characteristic of this particular ground station although on one of the Andenes flights, when the balloon was very close to the receiving station, it was noted that there was a bearing error of 15 or 20 degrees with a very strong signal, and the balloon clearly within eyesight of the station. However, this may have been due to the distortion of the signal by twisting of the long antenna in atmospheric sheer layers or refraction around the mountains or coastline lying between the station and the balloon.

E. Data Reduction.

The entire data acquisition scheme for Pocibo is shown in Figure 31. The data is first recorded on magnetic tape at the ground station. The tapes are brought back to the Physics Department for analysis and are played back at 7-1/2" per second through a synchronizer and conditioner, Figure 32. The playback speed is four times the recording speed. The conditioner punches a paper tape which provides a suitable input for computer analysis.The punched paper tape is indexed at the beginning with a notation giving the flight number, the reel number, the side number, the date, the time (time and date are referenced to the start of the paper tape), the bits per frame, time per frame and the sync code. The sync word code as mentioned earlier contains the Pocibo flight number.

The punched paper tapes are read into the CDC 160 computer using its paper tape input reader at the Numerical Analysis Center at the University of Minnesota. The sync program decommutates the data by locating the sync word and arranging the bits in the correct order. It first reads the flight format from the paper tape, sets up its internal constants and writes the flight format on magnetic tape. Then it reads in 512 six bit words or 64 frames. It finds the bit position where in successive frames the sync word occurs most often. Then it writes the information on magnetic tape starting with a given sync word. Another program prints out the

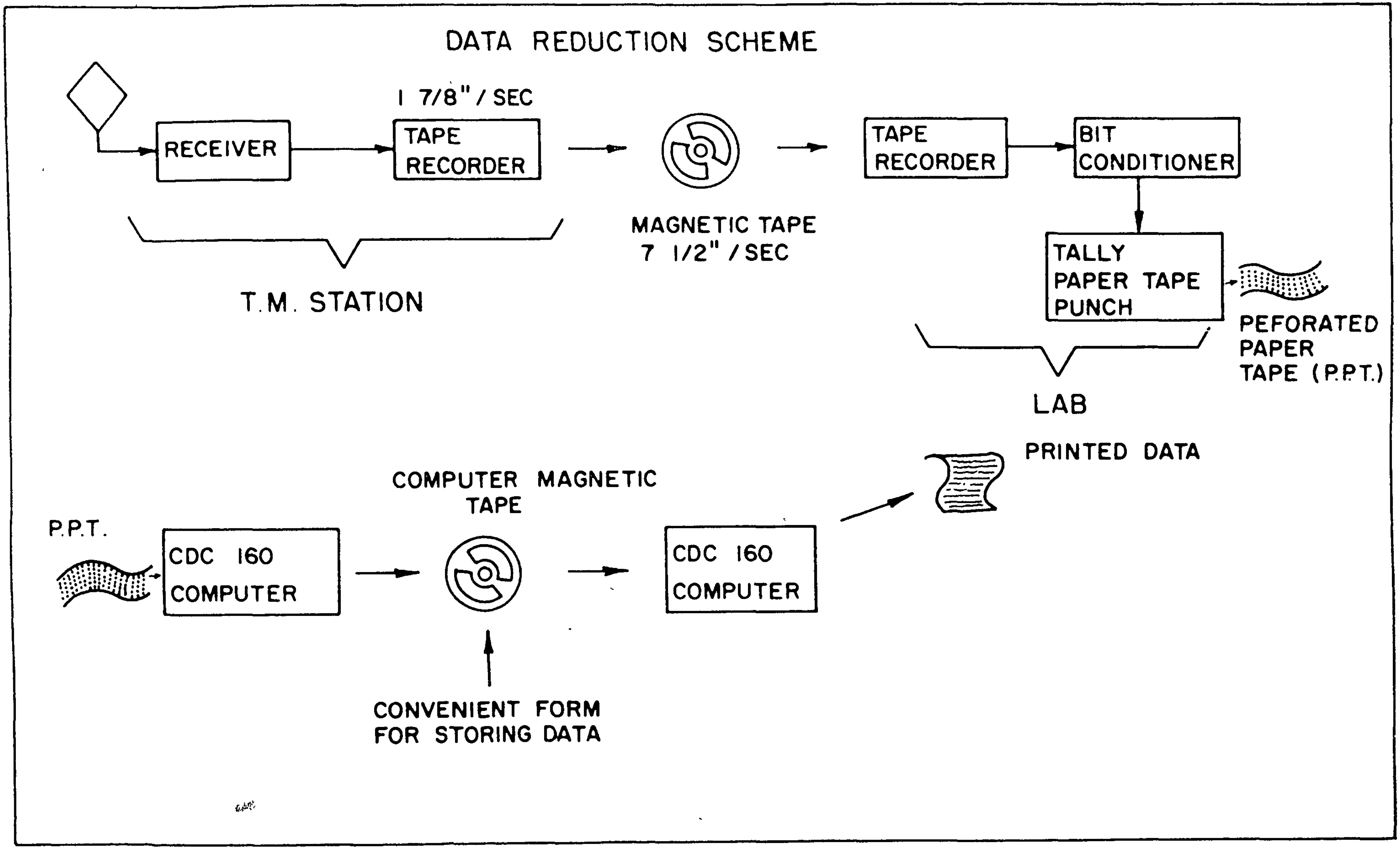
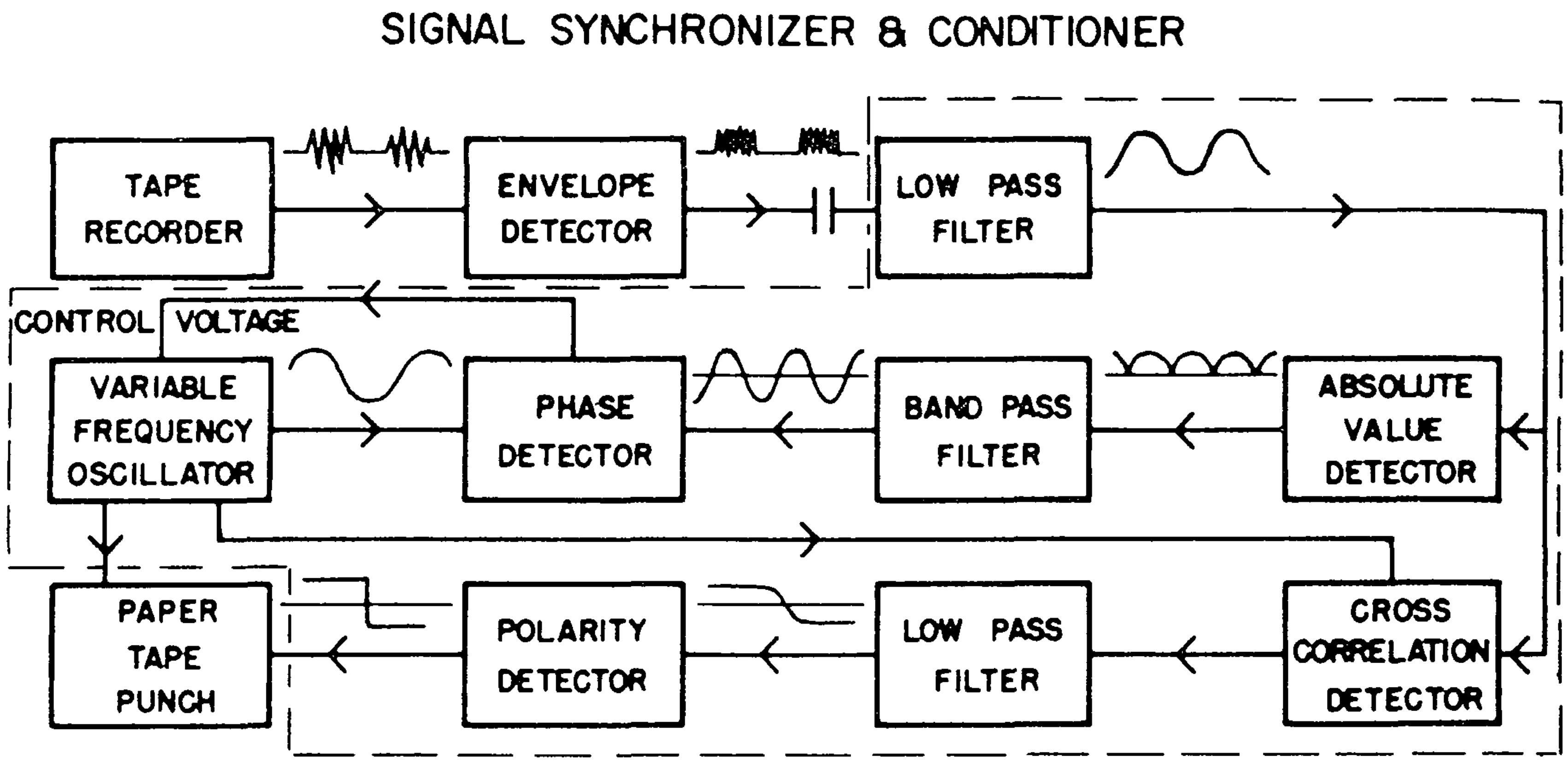

DATA REDUCTION SCHEME
1 7/8" / SEC
RECEIVER
TAPE RECORDER
T.M. STATION
MAGNETIC TAPE 7 1/2" / SEC
TAPE RECORDER
BIT CONDITIONER
TALLY PAPER TAPE PUNCH
PEFORATED PAPER TAPE (P.P.T.)
LAB
P.P.T.
CDC 160 COMPUTER
COMPUTER MAGNETIC TAPE
CONVENIENT FORM FOR STORING DATA
CDC 160 COMPUTER
PRINTED DATA

Figure 31



BLOCK DIAGRAM OF DATA PROCESSING

The data tapes are played back at 7-1/2" per second which is four times the recording speed of 1-7/8"/sec. The C.W. signal is detected and then filtered by a 64 cps cutoff low pass filter. The filtered signal is fed to the bit synchronizer and bit detector simultaneously. A full wave rectifier serves as the absolute value detector which doubles the frequency of the fundamental component of the bit rate. This forms a coherent frequency (not phase shifted like the filtered signal). The coherent frequency is filtered of sidebands and a local oscillator is phase locked onto it by a phase lock loop. The output from the local oscillator and the originally filtered signal are multiplied together in the cross-correlation detector. The unwanted products from the multiplier are filtered by a 32 cps cutoff low pass filter and what remains is a manchester coded NRZ signal. This signal is amplified and limited by the polarity detector. The reconditioned bits and the synchronizing signal drive the paper tape punch.

raw bits keeping track of the time by counting frames and multiplying by a constant of time per frame. This bit printout arranges the information and time in any desired spacing (see Figure 33).

Further programs are available to filter the decommutated data and compute rates on the various instruments. The filter program effectively selects the bit in each frame corresponding to the binary output of one of the instruments, then examines this bit in an adjacent sequence of five frames. It determines whether ones or zeros are in the majority and assigns this bit to the third or central frame and records the time. It then advances this sequence one frame at a time and in effect produces a moving average of the data. This procedure narrows the bandwidth and corrects and removes the effect of spurious bits when working with a counting instrument which has a fairly regular counting rate. The filtering program which begins with the magnetic tape output from the sync program writes another output tape containing filtered data. The final program is then the rate computation program. It inputs the filtered data and computes the rate for each counting experiment between bit transitions. If more than one bit transition occurs in the predetermined interval in which the rate is being computed, it averages the rate over the number of transitions in that interval. The computed rates are written on another magnetic tape. This tape is used for a paper printout of the rates.

The printed rates are then checked by manual means and cross-checked from the bit print-out. If the data has been derived from a very noisy signal, the sync program will still organize the frames, but in this case, the readout and rate computation is best done by hand. Also, difficulties sometimes occur with the paper tape reader of the computer which misses some data on the punch paper tape and causes some complications in the rate program. So far, the graphing of the various instrumental rates against time has been done by hand because the amount of data does not warrant devising a computer program for automatic digital plotting.

```
DATE    TIME                                             PUCIBO  2      REFL 1     SIDE 2
MO YR   UT      SYNC    I C  TEL  CH1  CH2     TEMP      AR  B      P  T
08 63 1010    100001  001  111  000  010  00  1  100  00  1  0  1  1  000000000000000000
              100001  001  111  001  010  01  1  001  00  1  0  1  1  000000000000000000
              100001  001  110  001  011  01  1  011  00  1  0  0  1  000000000000000000
              100001  001  111  000  011  10  1  011  00  1  0  0  1  000000000000000000
              100001  001  110  001  011  10  1  110  00  1  0  0  1  000000000000000000
              100001  001  110  000  010  11  1  001  00  1  0  0  1  000000000000000000
              100001  001  111  000  010  11  1  101  00  1  0  0  1  000000000000000000
              100001  001  111  000  011  00  1  000  00  1  0  1  1  000000000000000000
              100001  001  110  001  010  00  1  011  00  1  0  0  1  000000000000000000
              100001  001  011  000  011  00  1  110  00  1  0  1  1  000000000000000000
              100001  001  111  010  011  01  1  000  00  0  1  1  1  000000000000000000
              100001  001  110  011  000  01  1  010  00  1  0  0  1  000000000000000000
              100001  001  111  010  001  01  1  100  00  1  0  1  1  000000000000000000
              100001  000  110  010  001  01  1  110  00  1  0  0  1  000000000000000000
              100001  001  110  011  000  10  1  000  00  1  0  1  1  000000000000000000
              100001  001  110  010  001  10  1  010  00  1  0  0  0  100000000000000000
              100001  001  111  010  001  10  1  100  00  1  0  1  1  000000000000000000
              100001  000  110  011  000  10  1  110  00  1  0  1  1  000000000000000000
              100001  000  101  011  001  11  1  000  00  1  0  0  1  000000000000000000
              100001  000  110  010  001  11  1  010  00  1  0  1  1  000000000000000000
08 63 1014    100001  001  101  011  001  00  1  100  00  1  0  1  1  000000000000000000
              100001  000  101  011  000  01  1  110  00  1  0  0  1  000000000000000000
              100001  000  110  000  001  11  1  000  00  1  0  1  1  000000000000000000
              100001  000  101  001  011  00  1  010  00  1  0  1  1  000000000000000000
              100001  000  101  001  010  01  1  100  00  1  0  1  1  000000000000000000
              100001  000  100  000  010  10  1  110  00  1  0  0  1  000011000000000000
              100001  000  110  001  011  00  1  001  00  1  0  0  1  000000000110000000
              100001  000  101  001  111  10  1  011  00  1  0  1  1  000000000000000000
              100001  000  110  000  010  10  1  101  00  1  0  0  1  000000000000000000
              100001  000  111  001  011  11  1  111  00  1  0  1  1  000000000000000000
              100001  000  100  001  011  01  1  001  00  1  0  1  1  000000000000000000
              100001  000  001  110  010  10  1  010  00  1  0  0  1  000000000000000000
              100001  000  111  001  010  11  1  001  00  1  0  0  1  000000000000000000
              100001  000  100  001  011  00  1  111  00  1  0  0  1  000000000000000000
              100001  000  101  010  101  10  1  000  00  1  0  1  1  000000000000000000
              100001  000  101  010  100  11  1  010  00  1  0  0  1  000000000000000000
              100001  000  100  011  100  00  1  011  00  1  0  1  1  000000110000000000
              100001  000  101  010  101  01  1  101  00  1  0  1  1  000000000000000000
              100001  000  111  011  101  10  1  110  00  1  0  0  1  000000000000000000
              100001  000  110  010  100  00  1  001  00  1  0  0  1  000000000110000000
```

Figure 33

IV. SOME SCIENTIFIC RESULTS OF POCIBO.

A. An Interesting Balloon-Radiation Field Effect

Pocibo flight number 2 launched from Fort Churchill on August 26, 1963, which floated for one and a half days showed an interesting radiation effect on the balloon which was measured and evaluated independently by a blackball type radiometer and an air thermistor. The balloon pressure height vs. time is shown in Figure 34. The flight was launched at night and when the balloon leveled at 7.6 millibars, the air temperature was measured to be -39° and the blackball equilibrium temperature -35°. The blackball was of the shielded type designed by Gergen of the University of Minnesota. The balloon floated level through the first sunrise on the morning of August 26 and due to a temperature drift of the ballasting device dropped all its ballast by approximately 1730 on August 26. After this, the balloon floated without any ballast. At the time of balloon sunset on August 27th at about 0200 UT, the balloon descended, but because it was equipped with a duct type appendix, it was prevented from taking in air. It came into static balance again at a pressure height of about 30 mb. At this point, the air temperature had gone down to -49° C but the blackball showed the radiation environment to have remained at -56° C. The super heat gain of the balloon, assuming that it behaved like the blackball was therefore 4.5% which appears to be enough to have brought the balloon again into static balance and to compensate loss of lift due to cooling at sunset. At sunrise at about 1050 UT on August 27, the sunrise superheat started the balloon upward and it eventually went all the way back to its original ceiling at about 8 mb. It again floated level until it was commanded down at 2100 on August 27. Balloons which take air on descent are even more subject to this radiation field environment than those from which air is excluded, but if air enters the balloon as it descends, this air mixes with the helium and the balloon

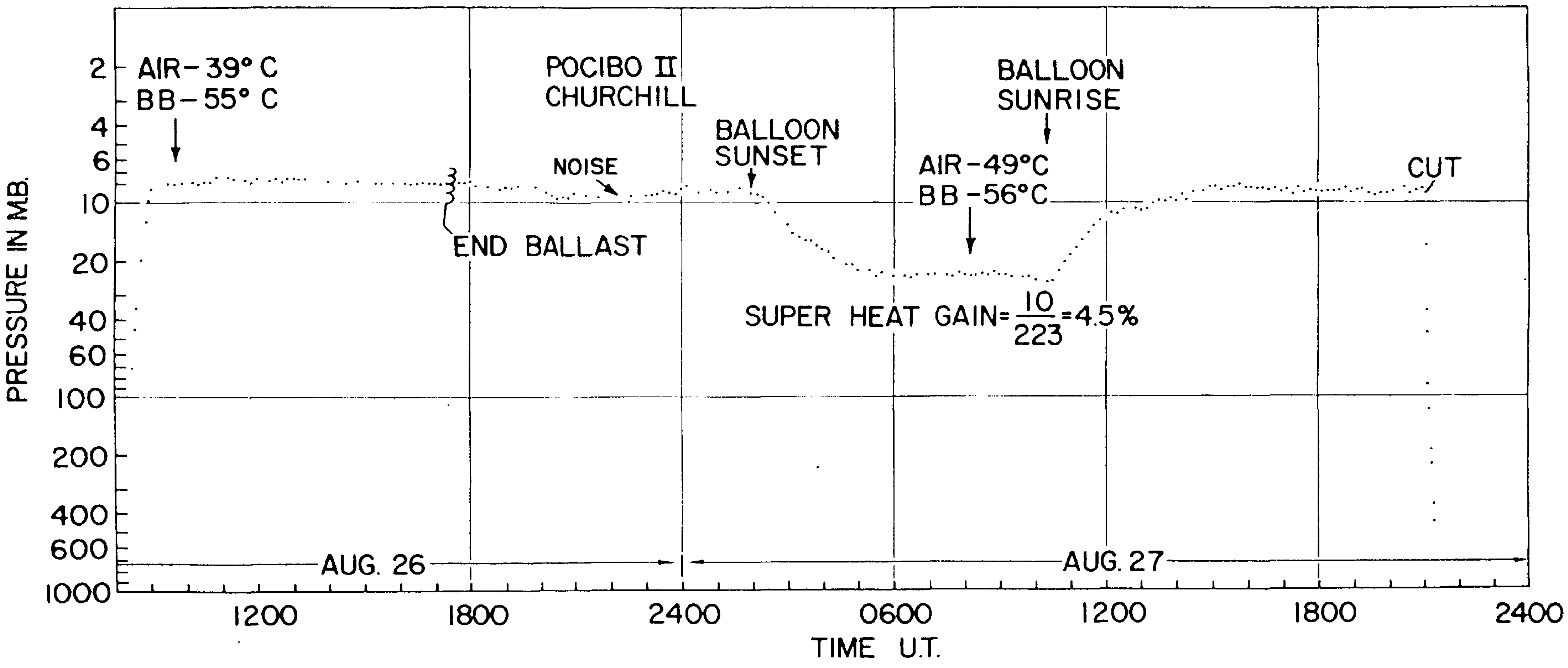

AIR - 39° C
BB - 55° C
POCIBO II
CHURCHILL
NOISE
END BALLAST
BALLOON
SUNSET
AIR -49°C
BB -56°C
BALLOON
SUNRISE
CUT
SUPER HEAT GAIN = 10/223 = 4.5%
PRESSURE IN MB.
2
4
6
10
20
40
60
100
200
400
600
1000
1200
1800
2400
0600
1200
1800
2400
TIME U.T.
AUG. 26
AUG. 27

Figure 34

will not return to its original ceiling. The duct appendix which was attached to the balloon well above the zero pressure level even with the balloon floating under ceiling altitude at 30 mb prevented any mixture of air. This flight, Pocibo 2 documents very clearly why a balloon will often remain aloft during the night withou ballast and conversely why a balloon given a certain amount of freelift may be brought into static balance before reaching its Archimedes ceiling because of the cooling in the temperature field at high level. That is, the balloon is stable against both descent and ascent in this region.

B. Cosmic Ray Total Ionization.

All of the flights carried cosmic ray detectors. For example, the ion chamber and counter combinations which have been flown at Minnesota on many hundreds of flights for cosmic ray monitoring were included on the Pocibo packages. In addition, particle detectors designed and built by Hofmann for measuring the low energy end of the primary proton and α-particle spectrum were used. Some results of the ion chamber readings on the Pocibo program are shown in Figure 35 where we see measurements made during the summer of 1963 and 1964 and in the spring of 1965 on the "Little Pocibo" program. Here we see the increase in ionization, particularl near the top of the atmosphere due to the increase in the primary galactic spectrum as the solar cycle advanced through solar minimum from 1964 to 1965. These measurements are analyzed and reported in detail elsewhere*.

C. The "Little Pocibo" Flights.

1. Introduction

Following the balloon failures at Barrow and Norway in 1964, it became evident that the probability of getting the large Pocibo payload to go to ceiling and stay for a reasonable amount of time was too small to warrant further attempts

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*Proceedings, Ninth International Cosmic Ray Conference, London, September, 1965.

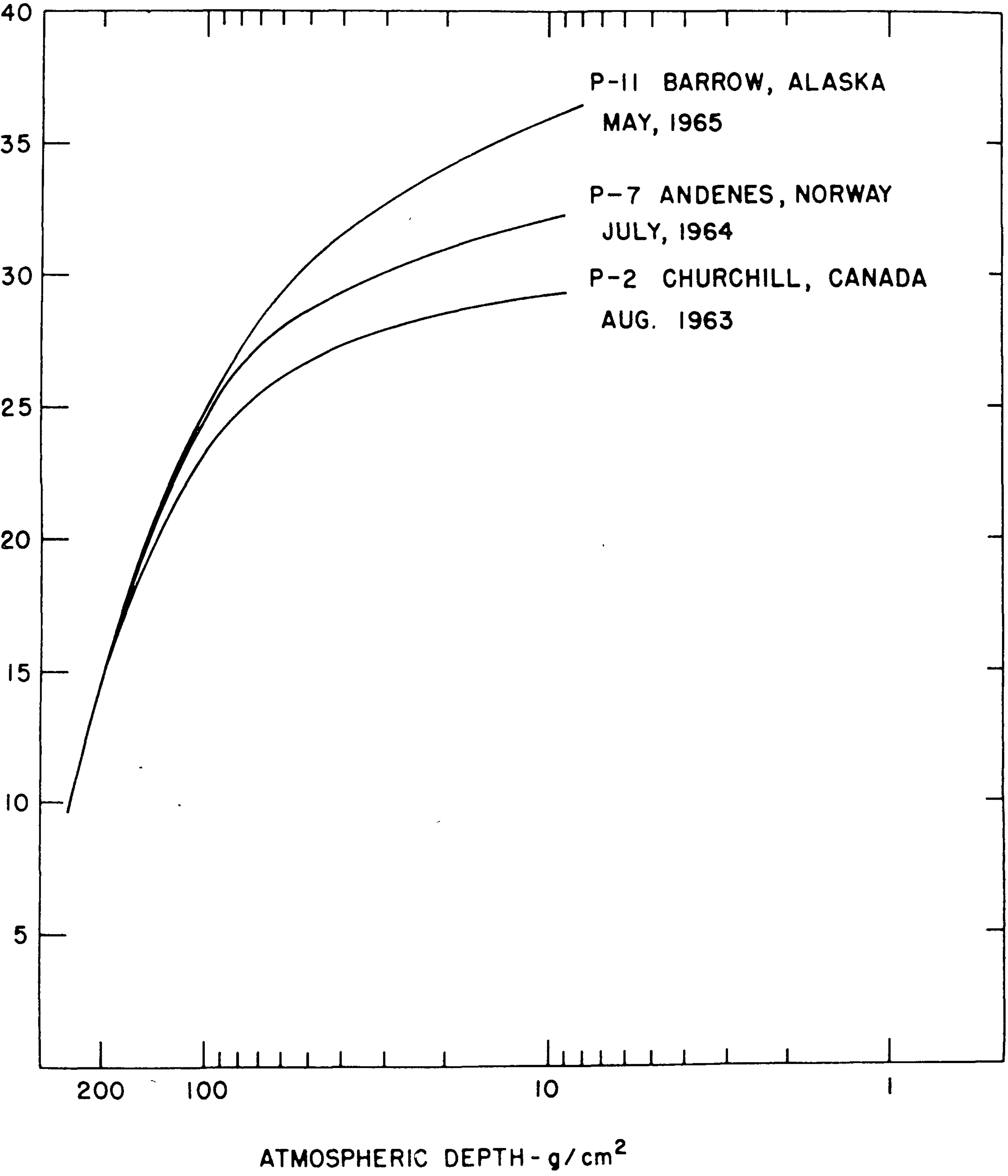
40
35
30
25
20
15
10
5
200
100
10
1
ATMOSPHERIC DEPTH - g/cm²
P-11 BARROW, ALASKA
MAY, 1965
P-7 ANDENES, NORWAY
JULY, 1964
P-2 CHURCHILL, CANADA
AUG. 1963

Figure 35

at this time. It was decided to scale down the payload and thus the balloon size by about a factor of 5.

A 100 lb. payload prototype was completed in September 1964. It consisted of a dE/dX - E particle analyzer, an ion chamber, geiger counter, geiger counter telescope, temperature measuring device, and an α-tron altitude-ballasting device. Its data system was the standard Pocibo digital system with 8 six bit words at 32 bits/sec, transmitted via the 1638 kc transmitter. The payload itself weighed about 70 lbs and could hold about 60 lbs of ballast.

The prototype gondola was flown on flight Pocibo 9 on 11 September 1964, utilizing a 300,000 ft^3 G. M. balloon. The balloon performed excellently, carrying the 100 lb load (including 30 lbs. of ballast) to a theoretical ceiling of 7-1/2 gm/cm^2. However, shortly after reaching ceiling, the transmitter modulation began to decrease and after about half an hour the signal was on constantly, i.e. zero modulation. The flight cut on schedule after eight hours; however, the landing impact rendered the package useless for further flights.

During the winter of 1964-65, three gondolas of this type were built, instrumented and checked out. They were flown from Barrow, Alaska on flights Pocibo 10, 29 April 1965; Pocibo 11, 4 May, 1965; and Pocibo 12, 12 May 1965. P-10 was carried aloft by a 3 x 10^5 ft^3 balloon which performed perfectly. However, the 1638 kc antenna did not deploy entirely and the signal was lost after one hour at a ceiling altitude of 7-1/2 gm/cm^2. All instruments functioned normally. P-11 also used a 3 x 10^5 ft^3 balloon with the antenna deployed before launch on a smaller rubber balloon. Everything functioned normally except that the balloon was a leaker and after twelve hours of total flight time was back on the ground. Valuable charged particle information was obtained at various altitudes.

After successfully testing a 10^6 ft^3 balloon with a dummy payload, P-12 was launched aboard a similar balloon with no ballast making the total payload only about 70 lbs. The balloon obtained a ceiling altitude of 127,000 ft(3-1/2 gm/cm^2)

and remained between 3-1/2 and 5 gm/cm^2 for ~30 hours. All instruments functioned normally on this unusually good flight.

2. Total Ionization and Proton Spectra.

Figure 36 is a plot of ion chamber rate vs. atmospheric depth during the ascent of flight P-12. The turn-up of the curve in the last few grams has some interesting implications concerning the primary cosmic ray spectrum during solar minimum. (The period around 12 May 1965 was the absolute maximum in neutron monitor counting rates during the present solar cycle). Whether or not the turn-up can be accounted for by the proton spectrum measured on P-12 is presently under scrutinization. Figure 37 is a preliminary plot of the dE/dX - E pulse height spectrum for the thin (dE/dX) and the thick (E) scintillation crystals from two hours at 3-1/2 gm/cm^2. The lines correspond to theoretical predictions for protons, deuterons and tritons. Figure 38 is a preliminary proton differential energy spectrum in the energy interval from 66 - 147 Mev at the top of the atmosphere, utilizing the measured secondary deuterons and tritons to correct for the secondary protons present at 3-1/2 gm/cm^2 atmospheric depth. Also shown is the spectrum measured in 1963 indicating the increased influx of protons during absolute solar minimum.

3. Measurement of the Isotopic Composition of Helium Nuclei in the Primary Cosmic Radiation in the Energy Interval 80-150 Mev/nucleon.

On May 12, 1965, a dE/dX - E scintillation counter device was launched on a balloon from Barrow, Alaska (69.5° N geomagnetic lat.) as a part of the IQSY polar circling balloon (POCIBO) project. Total flight time was about 31 hours with 26 hours of good data between 3.5 and 4.5 gm/cm^2 atmospheric depth. On this date the Deep River neutron monitor and the OGO-A ionization chamber in free space* indicated the highest counting rate during the current

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*See "Studies of Primary Cosmic Rays with Ionization Chambers", S. R. Kane, J. R. Winckler and R. L. Arnoldy, Proceedings of the London Cosmic Ray Conference, September, 1965.

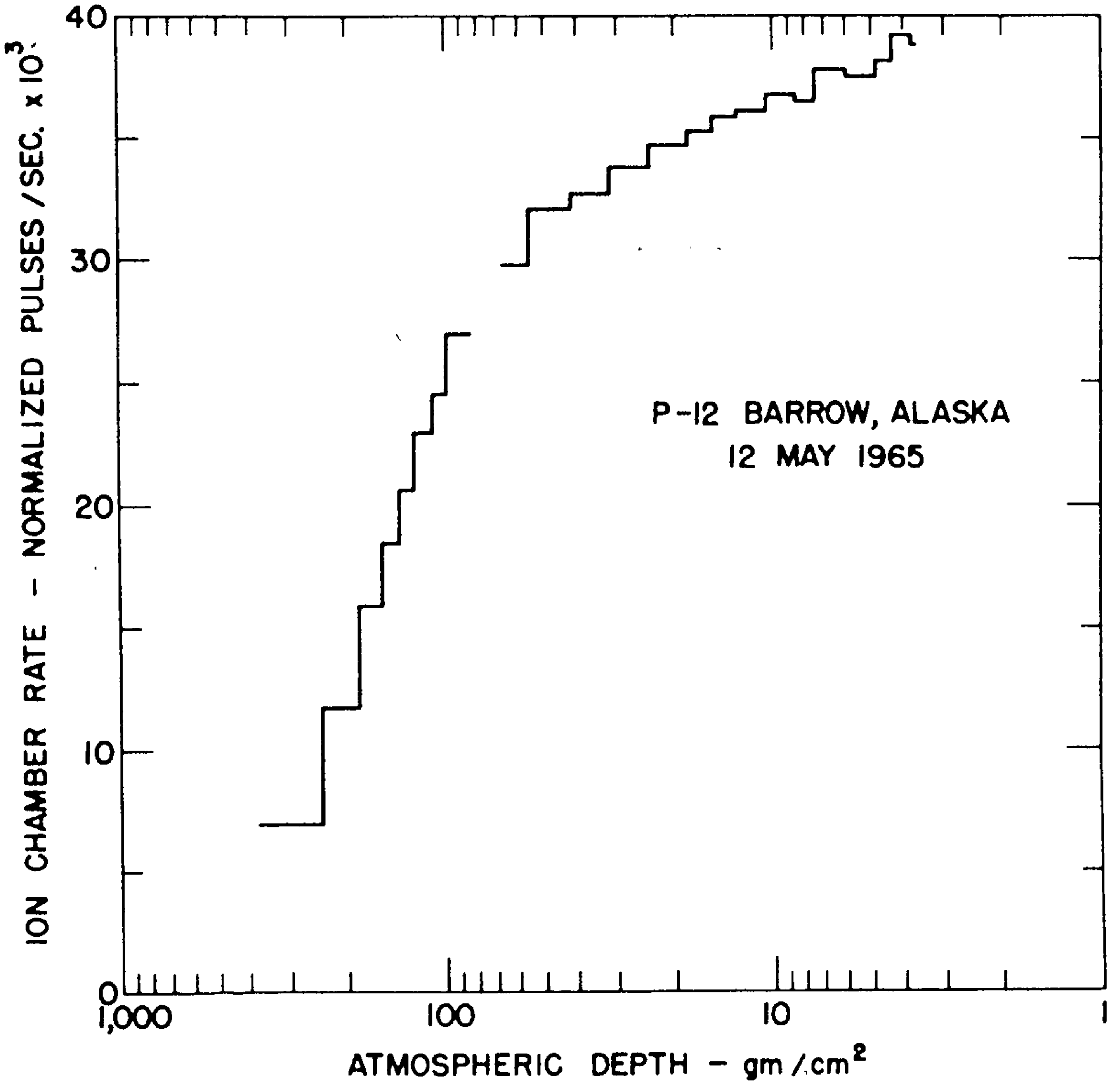

ION CHAMBER RATE - NORMALIZED PULSES / SEC. x 10^3
0
10
20
30
40
1,000
100
10
1
ATMOSPHERIC DEPTH - gm / cm^2
P-12 BARROW, ALASKA
12 MAY 1965

Figure 2

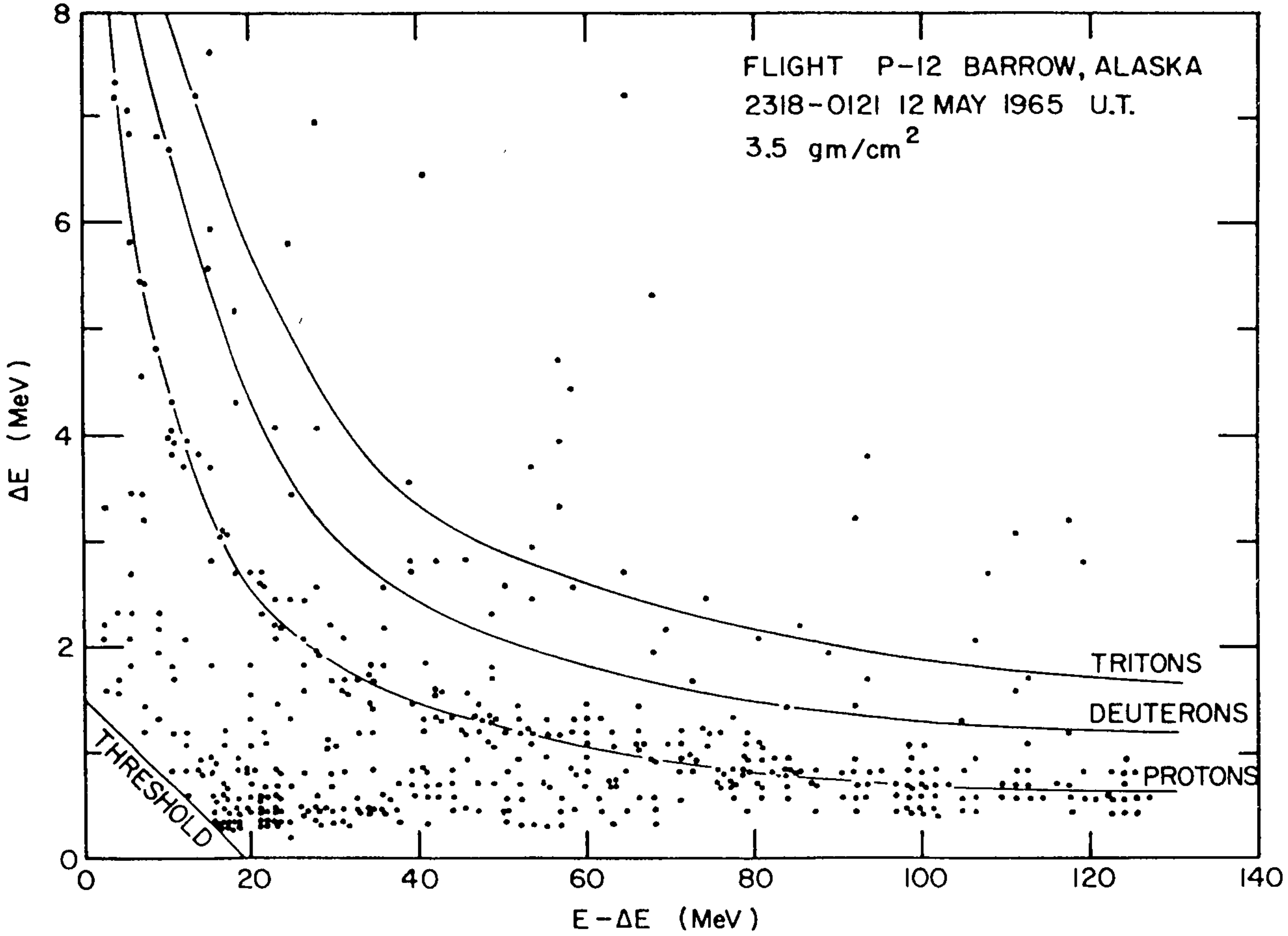


Figure 37

(No p. 80)

solar cycle. Thus the flight was made at absolute solar minimum in terms of particle influx. During the flight, the detector measured the spectrum of protons from 10 - 120 Mev at the detector, and helium nuclei from 25 - 100 Mev/nucleon at the detector. The inherent mass resolution of the detector and the increased amount of data gathered (220 helium nuclei), compared with previous balloon measurements, permits the energy spectrums of the two resolved isotopes He^3 and He^4 to be evaluated separately and thus to examine for the first time, the dependence of the ratio He^3/He^3+He^4 on energy and rigidity.

Figure 39 is a two-dimensional pulse height distribution from the dE/dX - E scintillation counters showing all events in the low gain helium mode during 26 hours of the flight. The smooth curves are the theoretical positions of the He^3 and He^4 lines. Background due to nuclear interactions in the crystals is only a serious problem below 100 Mev total kinetic energy and this data has been excluded from the analysis. Data in the region >25 Mev/nucleon from the 26 hours is shown as a mass histogram in Figure 40. Also shown are Gaussian distributions with 10% half-widths, the estimated resolution of the dE/dX scintillator for particles of this energy. Figures 41 and 42 show the differential energy/nucleon and rigidity spectrums of the He^3 and He^4 components taken separately and grouped together and treated as He^4. The data has been extrapolated to 0 gm/cm^2 using appropriate range energy data for the two species and the only flux correction amounted to an 8% increase due to atmospheric absorption and production by heavier nuclei, using the data of Freier and Waddington (1965). Also given in Figures 41 and 42 are the ratios He^3/He^3+He^4 in terms of energy/nucleon and rigidity. Over the interval from 80 - 150 Mev/nucleon, the ratio appears to be constant with energy/nucleon, having a value of .19 with a statistical deviation of ± .05 at any one energy/nucleon and ± .035 if all particles are grouped together. The rigidity spectrums overlap around .8 Bv giving a ratio of .39 ± .09 and the shape of the spectrums suggest that the ratio increases with decreasing rigidity and may be as high as .5 at .4 - .5 Bv.

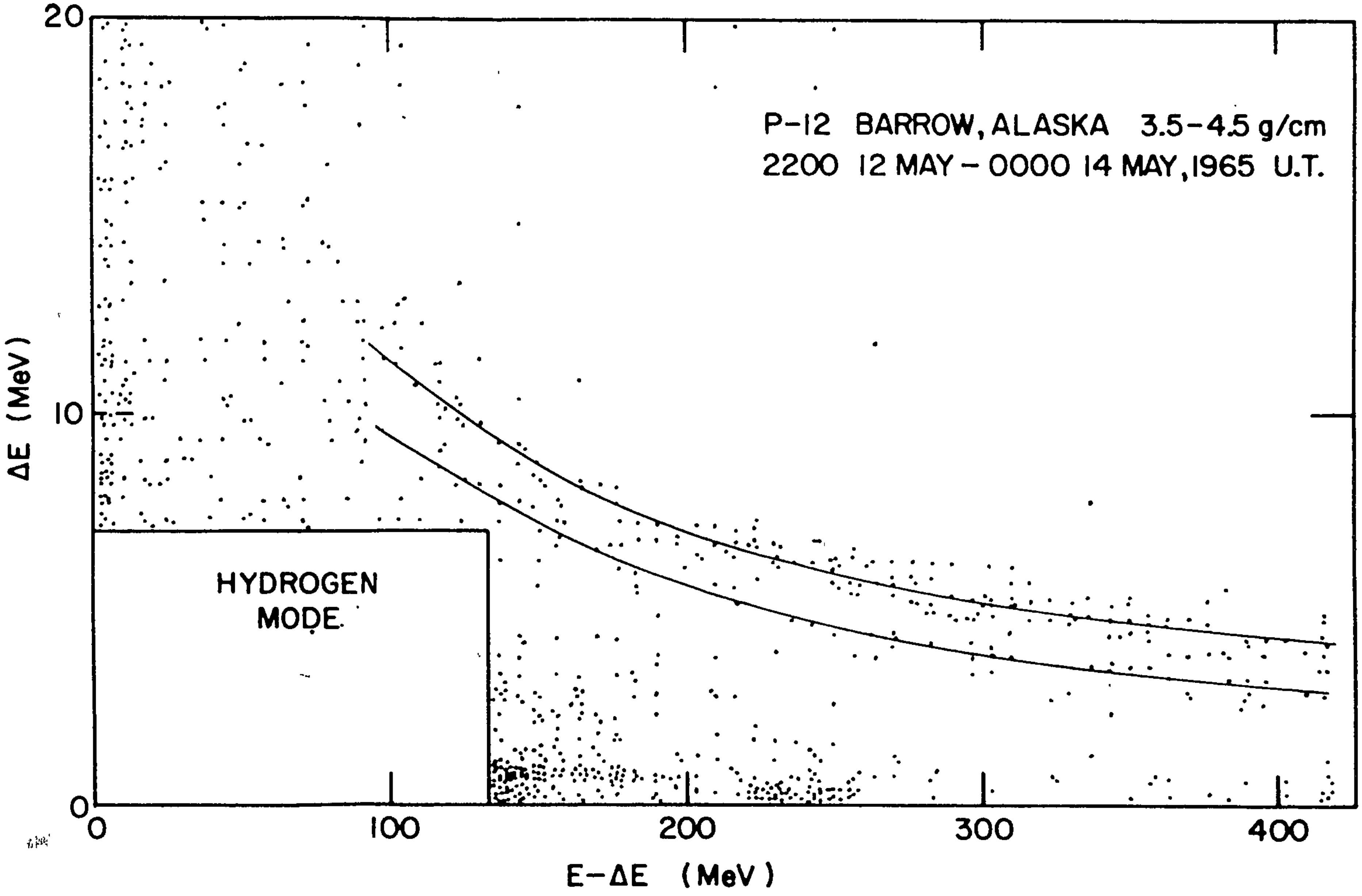

P-12 BARROW, ALASKA 3.5-4.5 g/cm
2200 12 MAY - 0000 14 MAY, 1965 U.T.
HYDROGEN MODE
ΔE (MeV)
20
10
0
E-ΔE (MeV)
0
100
200
300
400

Figure 39

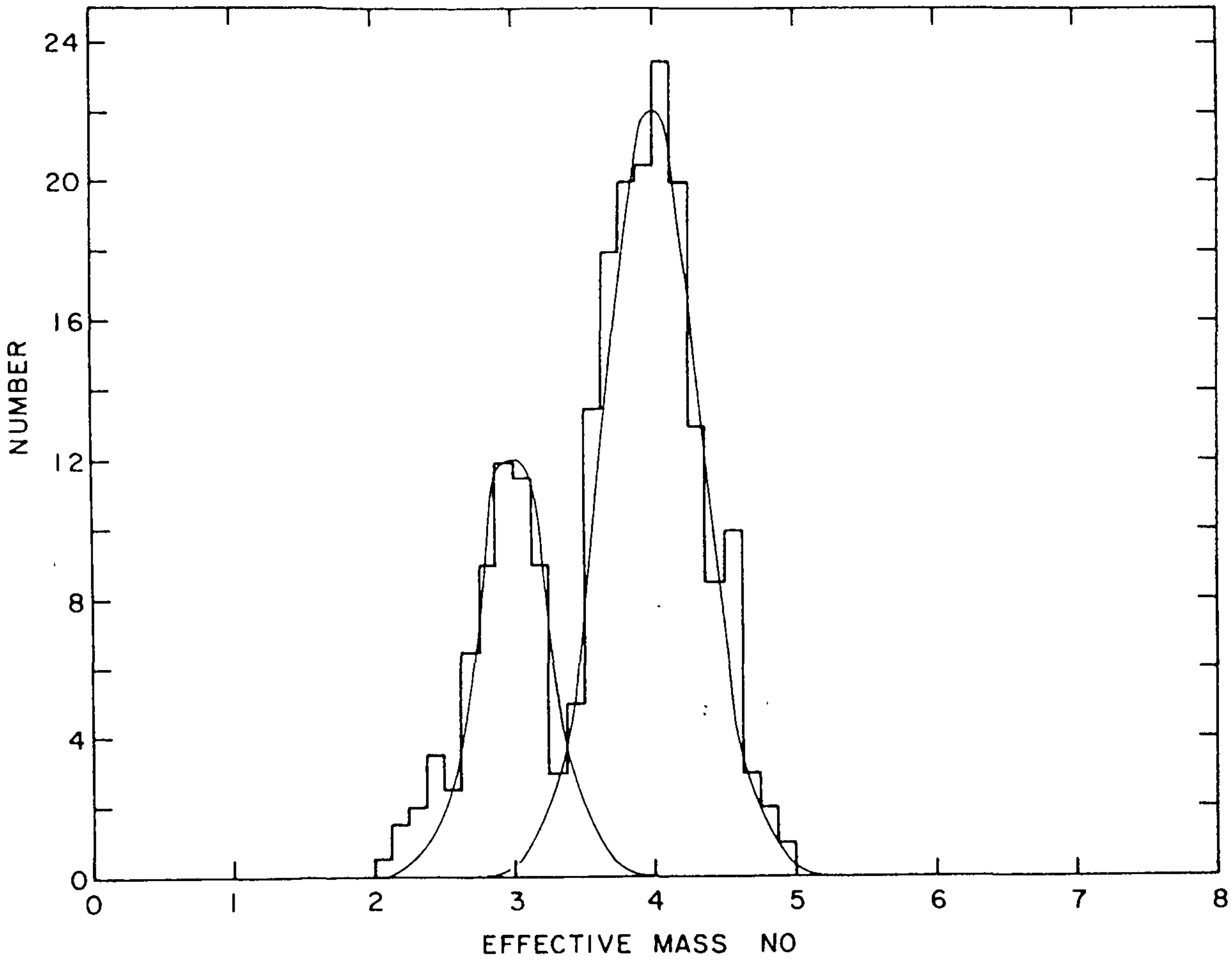


Figure 10

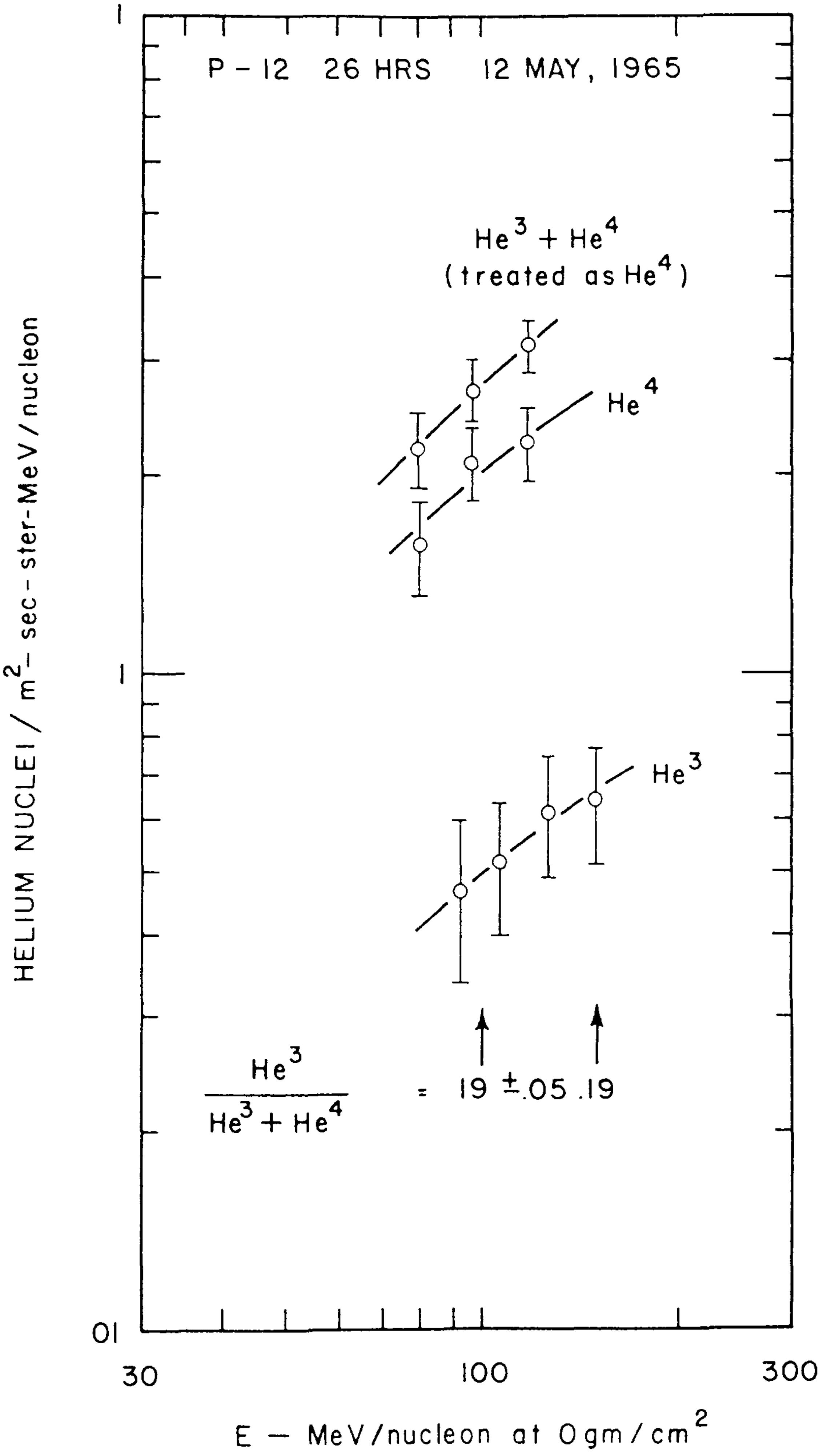
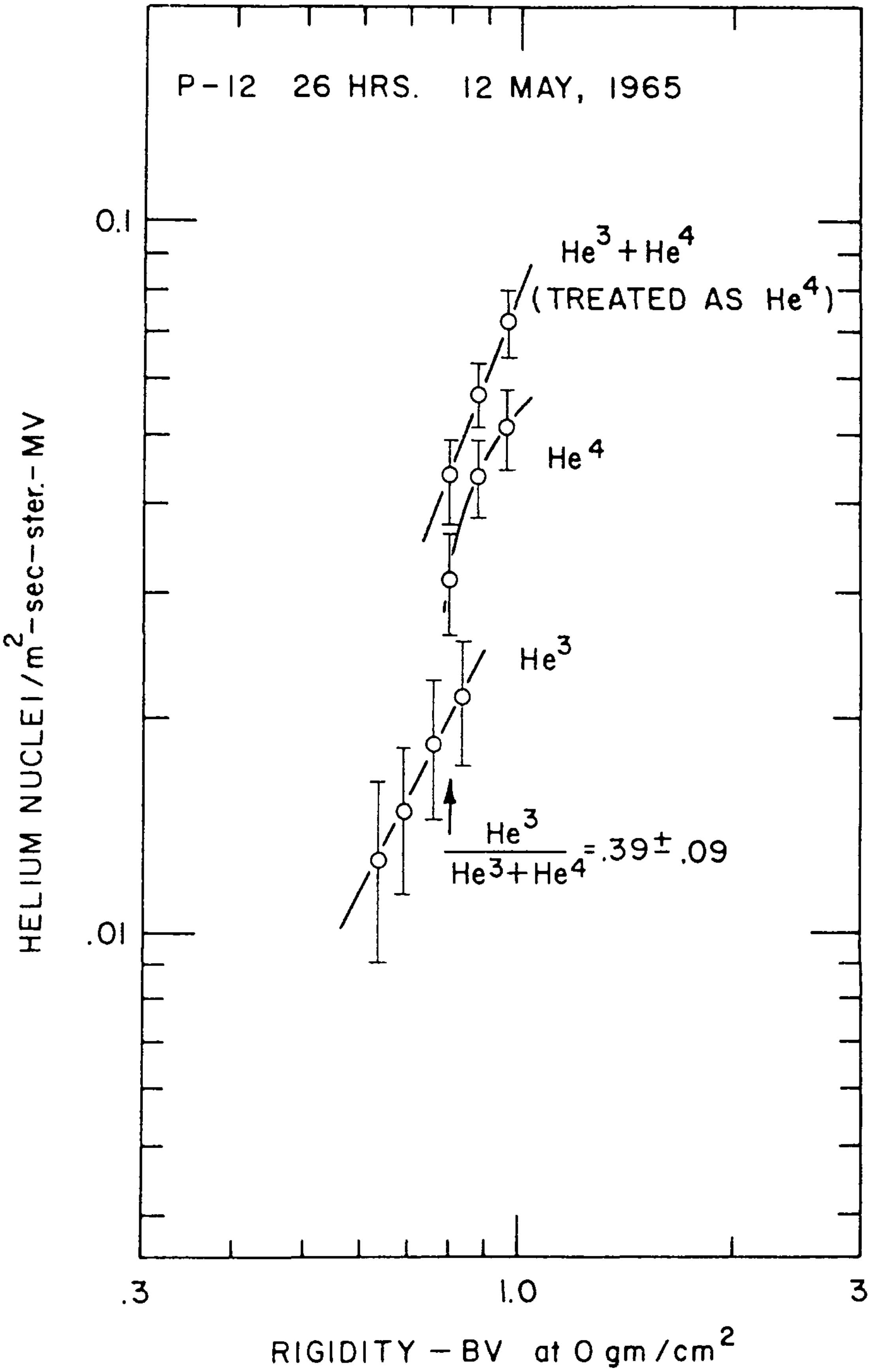

P - 12 26 HRS 12 MAY, 1965
$He^3 + He^4$ (treated as He^4)
He^4
He^3
$\frac{He^3}{He^3 + He^4}$ = 19 ± .05 .19
HELIUM NUCLEI / m^2 - sec - ster - MeV / nucleon
1
1
01
30
100
300
E — MeV/nucleon at 0 gm/cm^2

Figure 41


P-12 26 HRS. 12 MAY, 1965
HELIUM NUCLEI/m^2-sec-ster.-MV
0.1
.01
$He^3 + He^4$
(TREATED AS He^4)
He^4
He^3
$\frac{He^3}{He^3+He^4} = .39 \pm .09$
.3
1.0
3
RIGIDITY – BV at 0 gm/cm^2

The He^3/He^3+He^4 ratio measured at the earth is dependent on the cosmic ray source spectrum, interstellar fragmentation of He^4 and heavier nuclei, propagational effects such as energy loss by ionization in interstellar hydrogen and acceleration or deceleration in interstellar magnetic fields, and local modulation by solar influences. The scarcity of He^3 in most stellar atmospheres implies that the major source of He^3 is spallation of He^4 and heavier nuclei in passing through interstellar hydrogen. It is of interest to note that mass spectrometer measurements of helium nuclei in a dozen iron meteorites revealed a mean He^3/He^3+He^4 ratio of .20 ± .03 (Signer and Nier, 1962). Since these data were obtained from the interiors of large meteorites, they are presumably insensitive to the primary cosmic ray abundances as the outer layers where such particles stop were burned away by passage through the atmosphere. This central concentration of He^3 is thought to be due mainly to high energy cosmic ray protons causing evaporation of iron nuclei. Thus it is the inverse of the process by which heavy nuclei in the cosmic radiation produce He^3 by collision with interstellar hydrogen. The similarity of this ratio to that measured in the cosmic radiation is further support for the hypothesis that He^3 is a spallation rather than source product. Neglecting spectral changes due to energy loss or gain processes in interstellar space, one would expect the energy/nucleon spectrum of He^3 to be similar to that of He^4 in the near interstellar space free from solar modulation. The fact that the spectrums shown in figure (41) are the same indicates that at least at solar minimum the solar modulation has little effect on the observed He^3/He^3+He^4 ratio and it is thus very nearly the interstellar ratio.

From several diffusion calculations of the path length in interstellar hydrogen as a function of the ratio He^3/He^3+He^4, (Appa Rao, 1961; Foster and Mulvey, 1963; Dahanayake et al, 1964) and using our measured ratio at solar minimu, we estimate the path length to be 6.5±1.5 gm/cm^2 in the energy range 80-150 Mev/nucleon. Dahanayake et al (1964), utilizing emulsions, found a ratio of .18 ± .05 in the energy interval 160 - 370 Mev/nucleon at high latitude in 1962, and Hildebrand et al (1963) report a ratio of only .06 ± .03 in the energy interval 255 - 360 Mev/nucleon in 1961. Since considerable discrepancies appear to exist between these measurements and because the energy range is higher, little can be said about the energy dependence or solar modulation dependence of the ratio by a comparison of these values with those reported here. One might expect the ratio at 80 - 150 Mev/nucleon in 1965 to be significantly higher than the ratio at 160 - 370 Mev/nucleon in 1962 because (1) The path length in interstellar hydrogen may be energy dependent, causing the ratio at lower energy to be higher. (2) Most theories of solar modulation predict a maximum in the ratio at solar minimum. From our data alone we note that the observed energy/nucleon spectrum of He^3 is similar to that of He^4, and that the measurement was made as close as possible to solar minimum in terms of particle influx. Neglecting spectral changes due to energy loss or gain processes in the interstellar medium, one would expect the energy-nucleon spectrum of the two species to be similar in the near interstellar space free from solar modulation. Since the spectrums also appear similar near the earth, one concludes that at solar minimum, the modulation has little effect on the observed He^3/He^3+He^4 ratio and it is thus probably close to the interstellar value in this energy interval.

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V. THE LOGISTICS OF THE LAUNCHES AND THE TRACKING OPERATION.

The first possible wintertime Arctic launch site investigated was Thule, Greenland. In September 1963, representatives of the balloon launching contractor, of the Air Force and of the University of Minnesota visited Thule Air Force Base --

and discussed the problem of balloon launches. It was determined that certain areas in the air base would be indeed suitable for balloon launches and that between storms there were calm periods when a large balloon might be released from this location in mid-winter. Also, the air base is frequently serviced by air, and freight and personnel could be transported from the United States. The problem of a telemetry site was also investigated and one of the buildings formerly used as a meteorological station was examined. The cooperation of the U. S. Army Arctic Test Center was helpful in this respect. The next step was the requesting of permission to launch Pocibo type flights from Thule Air Force Base. This request was officially made by the U. S. State Department of the Danish Government. The request was refused; however, because of a possibility that the balloons would overfly Soviet territory and this site could no longer be considered. This was regrettable as the Thule location is generally quite ideal for the Pocibo idea because it is often located near the center of the wintertime cyclonic vortex. The Thule location was subsequently used as a telemetry monitoring site during the summer operation in 1964. It proved to be, however, noisy and generally unsuitable for the low level 70 kc reception which Pocibo required.

The Barrow, Alaska site had been previously surveyed by Professor George Swenson of the University of Illinois, both for radio reception on 70 kc and for the balloon operation acting as consultant to the Pocibo project. Accordingly, arrangements were made through the Geography Branch of ONR, particularly Dr. Max Britton in Washington, D. C., to get the cooperation of the Arctic Research Lab, Barrow, Alaska for the operation. Barrow is accessible by ship only for a short time towards the end of the summer but almost daily air flights for both freight and passengers are available from Fairbanks on Wein Airlines. The decision was made to try some operations in the early spring of 1964 and accordingly the project was airlifted to Barrow from Fairbanks and personnel arrived on 24 January

1964, the same day that the sun appeared for the first time at Barrow. The Arctic Research Lab provided laboratory space of excellent quality, constructed a special telemetry building which was towed out onto the saltwater ice of a lagoon about 5 miles east of camp (See Figure 11), and generally housed and fed the project in fine order. The salt water ice with a radio ground which was simply sunk into the mud and salt water underneath the ice, made an excellent telemetry site which was far enough from the camp so that no RF noise disturbances were encountred. The balloon launches were carried out also on the lagoon ice not far from the telemetry building. The helium cylinders which had been airlifted to Barrow were mounted on a large sled and towed out near the launch site. Bulldozers graded off smooth places on the snow and the launchings took place without any major difficulties. One feature of this launch was the Pocibo launch sled which is shown in some of the accompanying photographs (Figures 2 and 11). This sled worked very successfully on the snow and launched the package unaided with a crosswind of 12 knots. The idea of this sled is that it merely chases the balloon and is arranged so that the package can be lifted out of the sled whenever the balloon is vertically over it. The sled supports the package until the balloon is able to lift it clear of the ground even when the entire assembly is travelling rapidly downwind. Experience with the sled on wheels in the Norway launches was not so favorable; however, as sudden jerks on the package tended to upset the cart.

Through the cooperation of the Arctic Research Laboratory, a second monitoring site was set up on the drifting station known as T-3 which in January-February 1964 was located about halfway between Barrow and the North Pole and was being serviced several times per week by air from the Arctic Research Laboratory at Barrow. A 70 kc monitoring station was set up in an abandoned radome at the T-3 station and monitored a number of the flights launched from Barrow. Although

Barrow proved to be an excellent site logistically, it was unfortunately too far from the center of the winter vortex to be useful for Pocibo flights. This was born out by the considerable amount of data studied during the Barrow operation. Daily 10 mb polar charts were obtained from the Stratospheric Research Branch of the U. S. Weather Bureau under the direction of Dr. Sid Teweles. Also, this group calculated trajectories for balloons from Barrow and forwarded them by teletype to the Arctic Research Laboratory. A considerable daily effort was put into examining the meteorology, the trajectories of the balloons, the height of the 10 mb pressure surfaces and the temperatures in the stratosphere. At no time during the spring period was a good Pocibo trajectory from Barrow forecasted. Some of the time Barrow was immersed in a jet stream between the Aleutian high and the Polar low and the airflow went down over Canada and into Northcentral U.S. The best trajectory that occurred during this period went across Hudson Bay and crossed the British Isles. This would have been too southerly for a Pocibo flight. At one point, the high pressure system moved over Alaska and trajectories began to curve around in the Alaskan Peninsula. Several launchings were attempted under these circumstances as they would be confined to territorial U. S. As mentioned earlier in this report, the International situation was such that proper arrangements had not been made with the Canadian authorities for overflights and the Pocibo operation at this stage had to be confined to territorial U. S.

Following the completion of the tests at Barrow with their unfortunate consequences with the balloons as delineated earlier, it was decided to try a different type balloon and to attempt some summertime launchings from another place. Negotiations were made with the Norwegian Space Commission and particularly through the University of Bergen Cosmic Ray Group headed by Dr. Harald Trefall who cooperated on the Norway launchings. The site selected was the Andøya Airfield located near the village of Andenes on the Island of Andøya on the north coast of Norway at a latitude of about 69.5 degrees. The entire operation was moved to Andenes with the heavy items going by water and flight equipment and personnel by air.

Four launchings were attempted during this series as outlined in the schedule of launches. The launching operation was very satisfactory from the runways of the Andøya Airfield. Two-way communications were established between Andøya and the other 70 kc monitoring sites at Thule, Greenland and Barrow, Alaska with the assistance of the Norwegian Communication Office at Andøya. It was generally found that Andenes was not very good for reception of 70 kc signals because of the high spheric level in the summertime and because of the apparent effect of the coastline and mountains on the propagation characteristics at these frequencies. It was intended that the balloons released from Andøya would drift westward across the north Atlantic,crossing Greenland and the northern Canadian Islands in the summer easterly flow. This flow, however, was found to be very light, averaging 10 miles per hour or less. Actually, this velocity is too low to make a long range flight possible. This operation was concluded at the end of July 1964.

POCIBO FLIGHT SUMMARY

POCIBO CODE NO.	DATE	LAUNCH LOCATION	COMMENT
1.	23 August 1963	Ft. Churchill Manitoba	1.5 x 10^6 ft.^{3} Raven Poly Balloon failed near ceiling. 70 kc antenna reel failed. Balloon burst 40,000 ft. on descent.
2.	26 August 1963	Ft. Churchill Manitoba	1.5 x 10^6 ft.^{3} Raven Poly Balloon. Excellent flight, 31 hrs. 70 kc antenna reel failed. Data from 95 MC channel. Unique radiation effect on balloon.
3.	3 March 1964	Pt. Barrow Alaska	1.5 x 10^6 ft.^{3} Raven Poly Balloon. Burst at 7.5 mb (109,000 ft.). 70 kc antenna drop O. K. Ballast O. K. Sig. O. K. Barrow and T-3.
4.	6 March 1964	Pt. Barrow Alaska	1.5 x 10^6 ft.^{3} Raven Poly Balloon leaked and was cut down after 7 hrs. by low blow. Ballast did not drop as programmed. Good Sig. at Barrow and T-3.
	13 March 1964	Pt. Barrow Alaska	1.5 x 10^6 ft.^{3} Raven Poly Balloon burst on release. Payload not airborne.
5.	8 July 1964	Andøya Airfield Norway	1.5 x 10^6 ft.^{3} Schjeldahl GT-66 Mylar Scrim Balloon. Leaked and dropped load in sea. 70 kc antenna did not drop as alt. less than 10,000 ft.
6.	12 July 1964	Andøya Airfield Norway	1.5 x 10^6 ft.^{3} GT-66 Balloon. Lost 165 lbs. lift prior to launch. Picked up load for approx. 10 ft. Payload saved.
7.	19 July 1964	Andøya Airfield Norway	1.5 x 10^6 ft.^{3} Raven Poly Balloon. Perfect vertical launch. Balloon burst 5.5 mb (above ceiling). Good 70 kc sig. All equipment working O. K.
8.	23 July 1964	Andøya Airfield Norway	1.5 x 10^6 ft.^{3} Raven Poly Balloon. Perfect vertical launch. Balloon burst 185 mb tropopause. 70 kc sig. good. All equipment working.

LITTLE POCIBO FLIGHT SUMMARY

POCIBO CODE NO.	DATE	LAUNCH LOCATION	COMMENT
9.	11 September 1964	Minneapolis, Minnesota	GM 3 x 10^5 ft.^{3}. 1/2 mil Polyethylene, 100 lb. gondola. (24 lb. ballast). Good launch. Balloon went to ceiling (7.5 gm/cm^2) and remained to cut 8 hours after launch. Transmitter modulation went down during ascent and after half hour at ceiling data was unreadable.
A.	18 March 1965	Pt. Barrow Alaska	Test flight, 100 lb. payload, 300,000 cu. ft. balloon, launched 2310 UT Flight went to theoretical ceiling, terminated by sunset and low altitude release, nine hours duration. Balloon behavior excellent.
10.	29 April, 1965	Pt. Barrow Alaska	300,000 cu.ft. balloon, 100 lb. payload, launched 0825 UT. Balloon leveled at 7.5 millibars, close to theoretical ceiling. Payload contained the Hofmann cosmic ray experiment (dE/dX+E) and ionization chamber. Payload functioned normally. Radio signal was weak, however, and signal was lost after about two hours at ceiling. Suspect 1638 kc antenna ball did not deploy all the way due to cold.
11.	4 May 1965	Pt. Barrow Alaska	300,000 cu. ft. balloon, 100 lb. payload same as flight 10, launched 1659 UT. Telemetry signal excellent. Balloon went to ceiling (7.5 millibars, 109,000 ft.) leveled for about 2 hours, then began a slow descent, presumably due to a small leak. Total flight time, 12 hours. Payload functioning--excellent. The slow descent, although not desirable for the primary objective, can be used in evaluating the effect of secondaries on the primary measurement.
B.	6 May 1965	Pt. Barrow Alaska	Test flight of 1 million cu.ft. balloon, launched 0243 UT, 145 lb. payload. Went to five millibar ceiling and remained level for duration for test, 12 hrs. (and was terminated). This flight made only for balloon test.
12.	12 May 1965	Pt. Barrow Alaska	1 million cu.ft. balloon, launched 2017 UT. This carried the complete payload like 10 and 11. Balloon performed perfectly floating between 3.5 and 5 millibars and remained airborne for 31 hours. Flight was terminated by timer and balloon was from 500-600 miles distant from Barrow at a bearing of approximately 320°. Down point estimated to be 77°N, 180°W. Preliminary analysis shows all instruments functioned properly so that flight is a total success.

VII. SUMMARY

This report describes how the Pocibo balloon program was set up at Barrow, Alaska, and at Andenes, Norway. It describes the problems encountered with the balloons, meteorology and the Arctic environment. The report particularly emphasizes the technical features of the program, including the unique 70 kc long range radio tracking and communications system. This system was successfully used to transmit data from the Pocibo balloons and signal levels and directional measurements were made. The report describes in detail the Pocibo flight gondola including the electronic design of the telemetry and data encoding system, power supply, the thermal properties, and the complement of scientific instruments. The construction of the ground station, receiving antennas and receivers, and the method of data reduction is described in detail.

The principal results of the Pocibo program consist of the experiences with the balloon launching, the Arctic conditions, the development of a sled for the purpose of launching the heavy payload, the development of a telemetry and data system, the development of a direction finding system, the development of a new α-tron pressure sensor and the exploration of the International problems in the circumpolar flights of the Pocibo balloons. The scientific results include observation of atmospheric radiation effects on the balloons documented by auxiliary temperature and radiation measurements, measurements of cosmic ray total ionization, and particularly on the Little Pocibo program, the studies of the low energy primary cosmic rays, including protons and helium. One of the highlights of the program is the excellent resolution of the isotopes He^3 and He^4 achieved in the Little Pocibo program in 1965.

VIII. ACKNOWLEDGEMENTS

Organizations:

The National Science Foundation, Atmospheric Sciences Section, for its very generous support and encouragement with the Pocibo program as part of the IQSY effort.

The Geography Branch of the Office of Naval Research and the Arctic Research Laboratory, Barrow, Alaska for their generous and effective support of the Pocibo and the Little Pocibo program at Barrow.

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The U. S. Army Arctic Test Center at Thule, Greenland for providing a facility for a Pocibo monitoring site during the summer 1964 operation.

Individuals:

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Mr. Dave Hofmann for organizaing the cosmic ray instrumentation on all of the Pocibo flights, for carrying out the Little Pocibo program with its highly successful cosmic ray measurements and for contributions to this report.

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Mr. Mike Weed for construction of x-ray experiments, the optical ozone experiments, flown in Norway in 1964, for some of the very first thinking about the digital data handling, and for assistance with many phases of the computer programs for data handling.

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